Introduction to the Gamma Spectrum Generator

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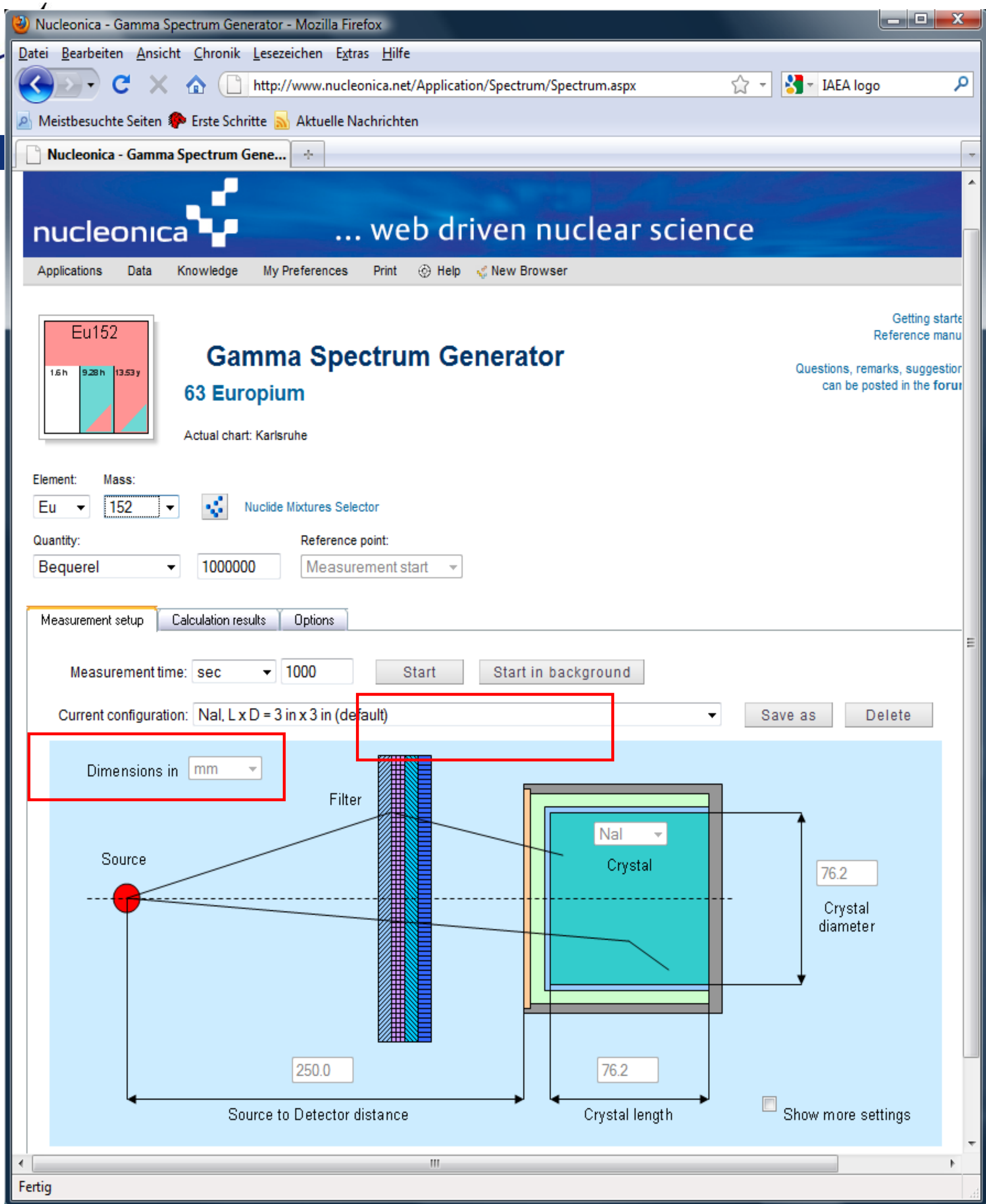


How to get to the GSG page:

1. Select <u>Applications->Gamma Spectrum Generator</u> from the Nucleonica's main menu

OR

2. Go to the Nuclear Science Applications Portal and select <u>Gamma Spectrum Generator</u> from the application list

Presentation outline

GSG in basic mode
- Modeling approach
- Introduction to the GSG features
- Experimental validation of the GSG

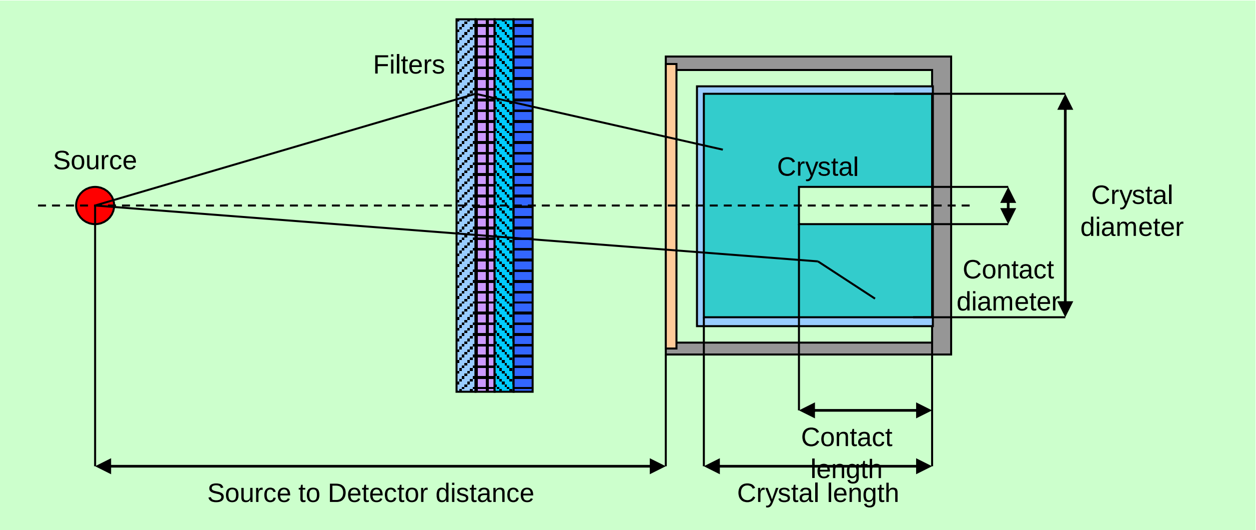
GSG-PRO
- Additional modeling features
- Introduction to coupled eMC-GSG-PRO simulations
- Examples of experimental validation

A simple application example

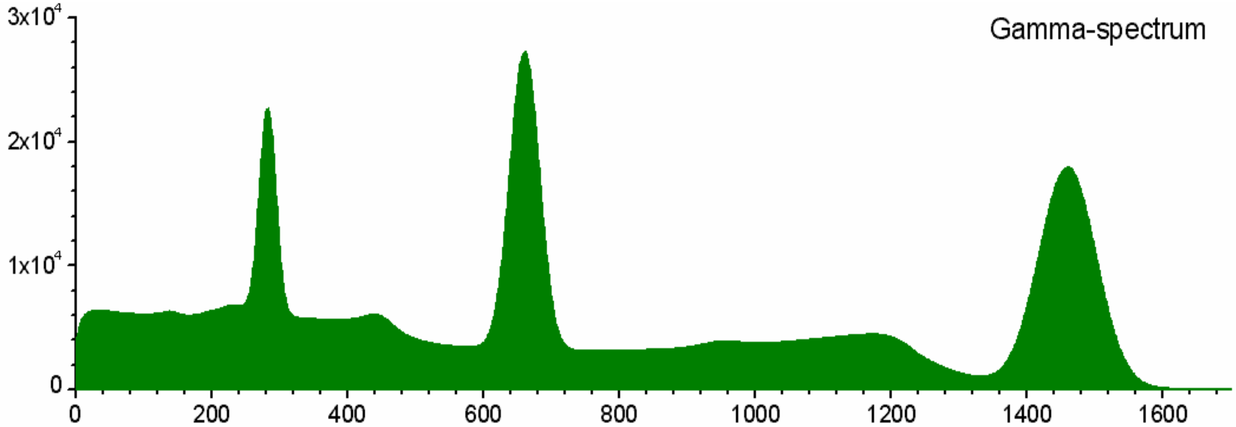
Exercises

GSG in basic mode: Modeling approach

Measurement setup model implemented:

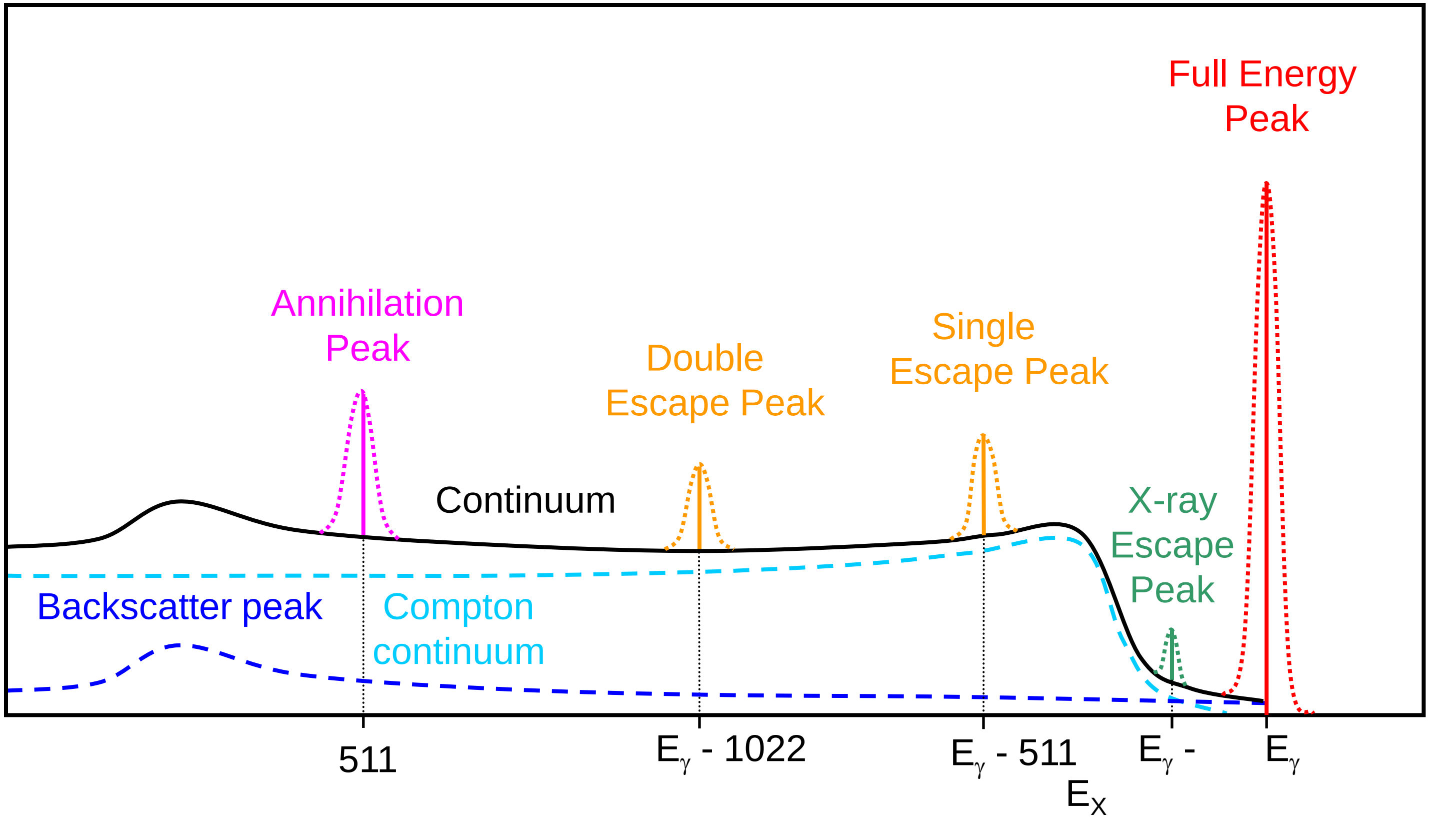


Spectrum modeling procedure:



GSG in basic mode: Modeling approach

- For spectrum modeling the GSG uses a comprehensive database of detector responses for gamma-ray energies from 10 keV to 10 MeV, which were obtained using extensive Monte Carlo simulations



- More details on the GSG simulation approach see in Nucleonica Wiki at http://www.nucleonica.net/wiki/index.php/Help:Gamma_Spectrum_Generator

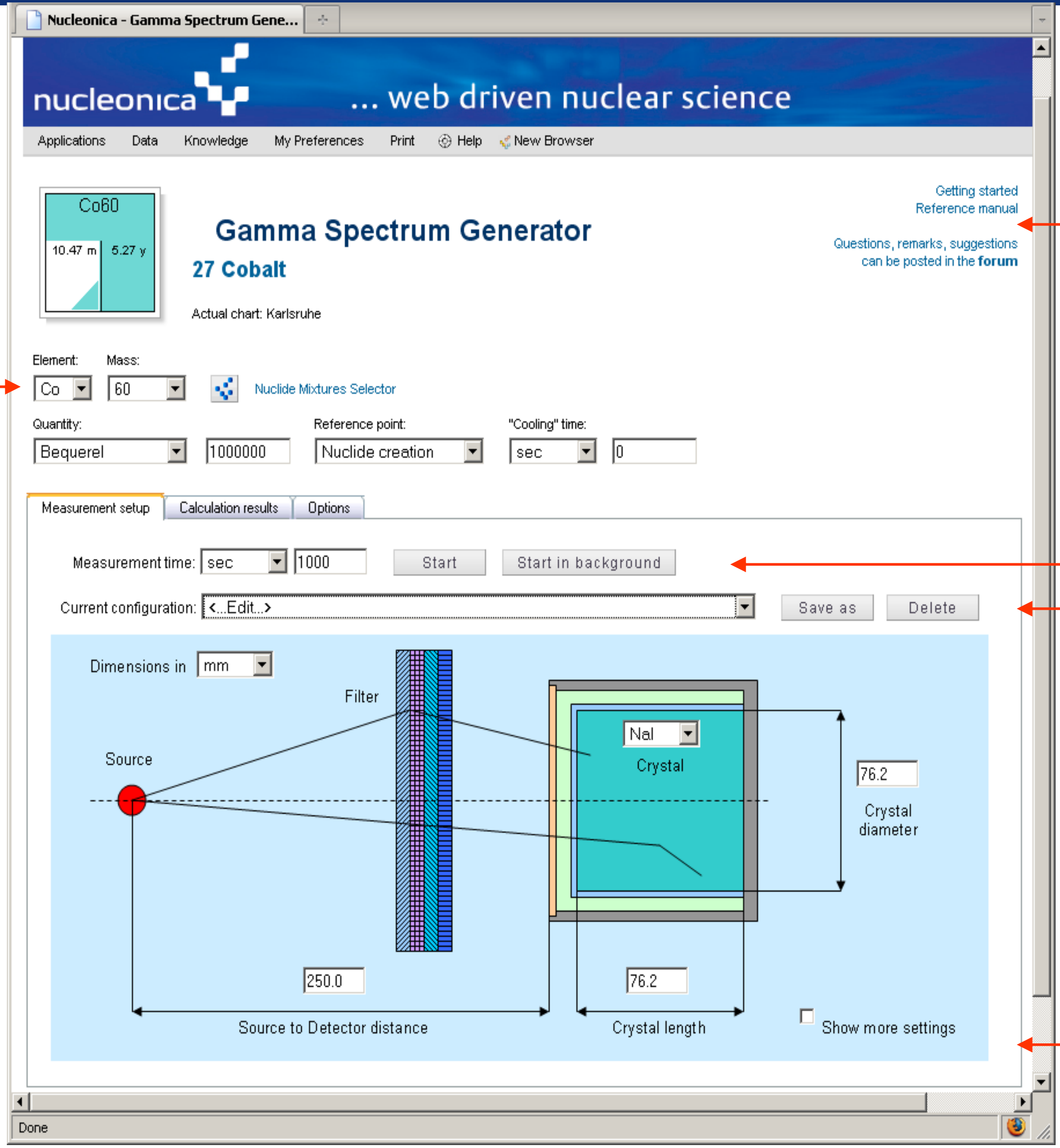
GSG in basic mode: GSG features

Select an arbitrary individual nuclide or a pre-defined mixture of nuclides as a radiation source

Specify the quantity (activity, mass or number of atoms) of a nuclide or a mixture either

- at the spectrum measurement starting point of time, or
- at the moment of nuclide/mixture creation.

In the last case, the controls for specifying duration of a source "cooling" time interval become available.



Links to the quick start and detailed reference manuals, as well as to the GSG user's forum

Press "Start" button to start a simulation

- Choose a suitable γ-spectrometer from 6 pre-defined configurations, including HPGe and NaI detectors, or
- Select "Edit" to create a new spectrometer.

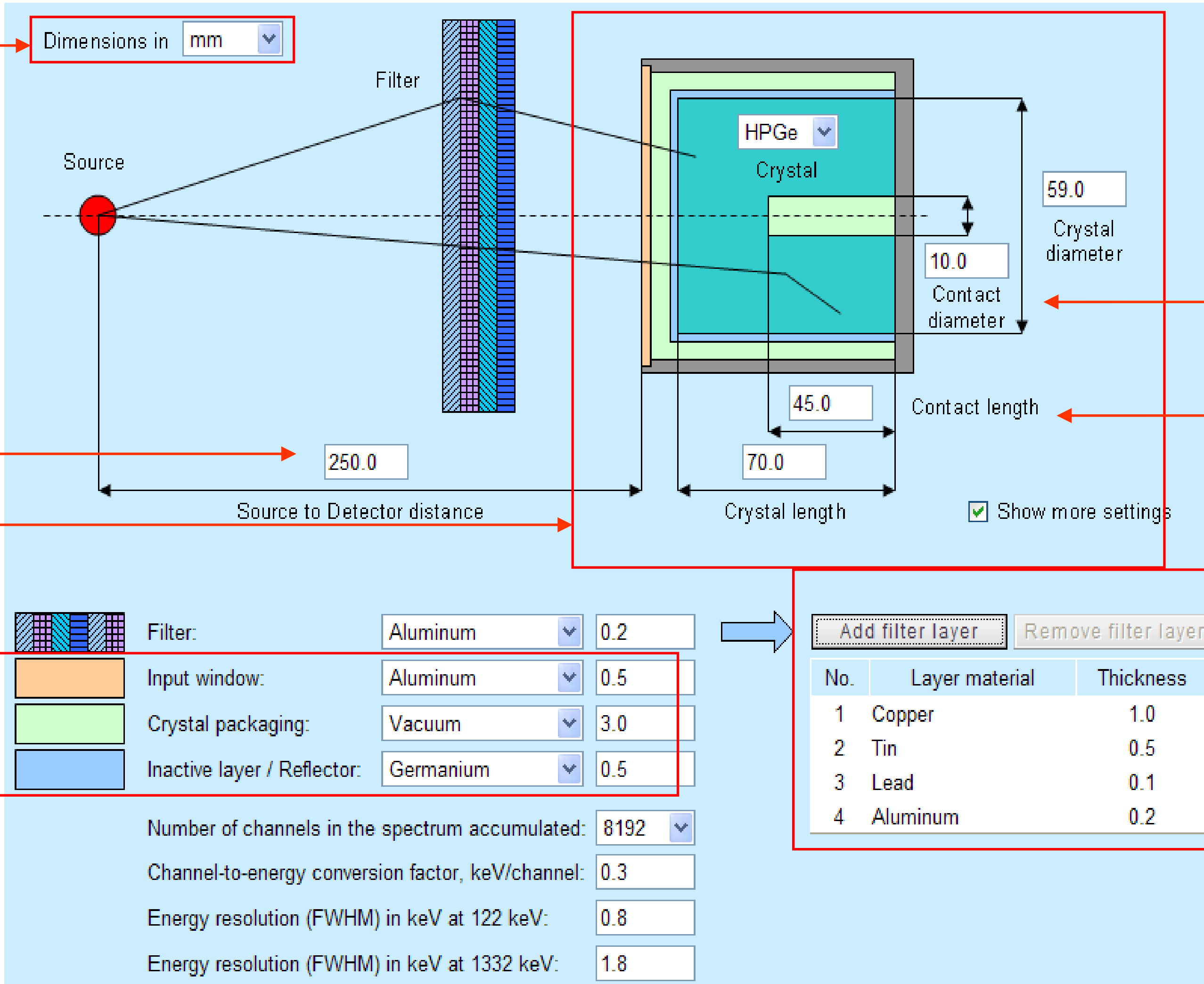
Tick the checkbox to get access to additional spectrometer settings

GSG in basic mode: GSG features

Configuring a new spectrometer:

Dimensions can be entered in “mm”, “cm” or “inch” units

The configurable parameters include the source-to-detector distance, as well as dimensions and materials of the detector construction elements.



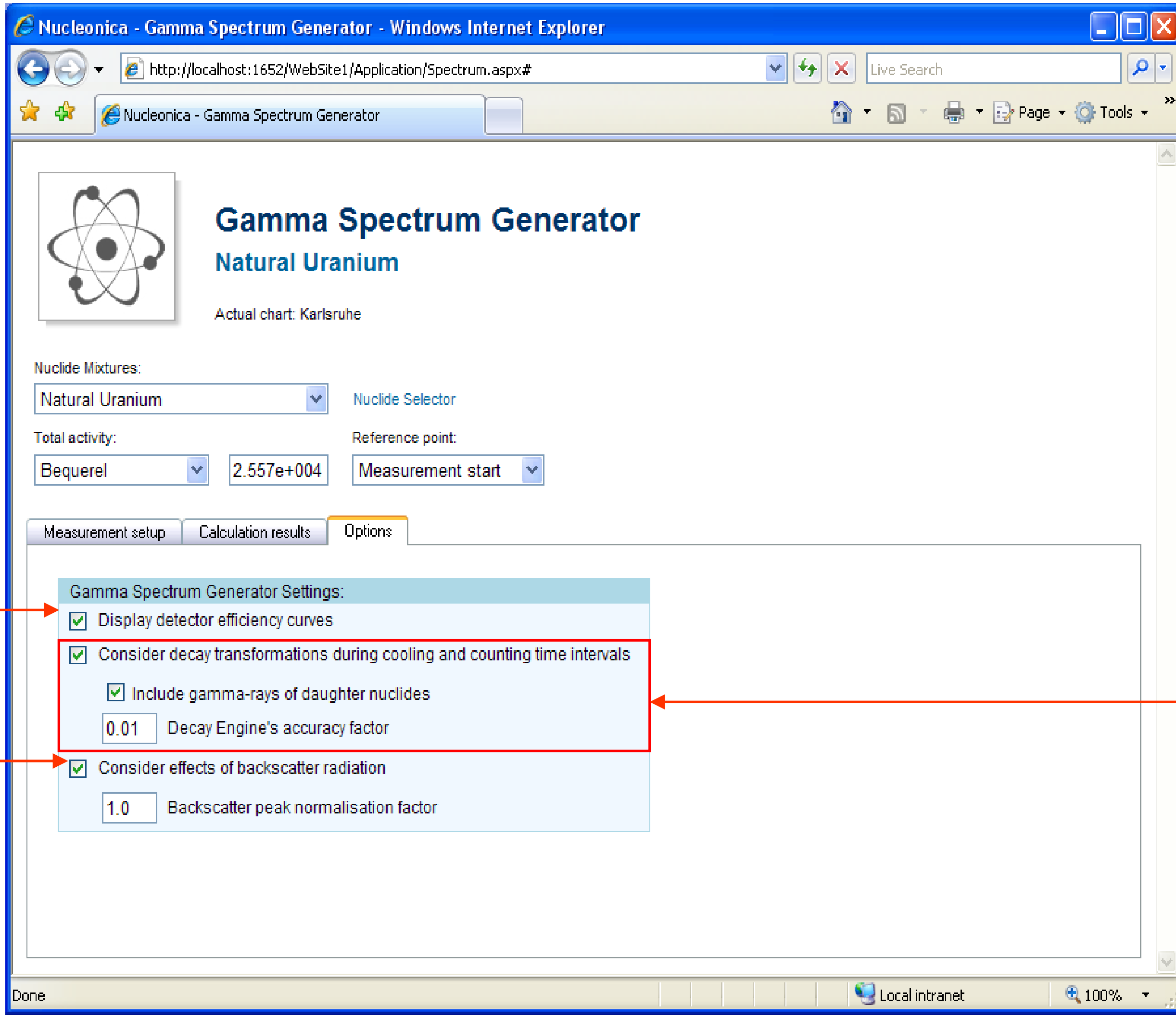
No.	Layer material	Thickness
1	Copper	1.0
2	Tin	0.5
3	Lead	0.1
4	Aluminum	0.2

The dimensions of a cylindrical contact at the rear side of the crystal (a construction feature of conventional coaxial HPGe detectors) can be specified

Up to 6 additional absorbing filters made of Al, Cu, Fe, Pb, Sn, or polyethylene can be placed between source and detector

GSG in basic mode: GSG features

Selecting calculation options:



Efficiency Graph can be activated in the Calculation Results output

The backscatter peak simulation can be switched on/off, and its contribution to the spectrum can be adjusted

Decay calculations can be enabled that will allow contributions from decay products, being accumulated during source cooling and spectrum measurement time intervals

GSG in basic mode: GSG features

Exploring calculation results:

Statistical number of counts

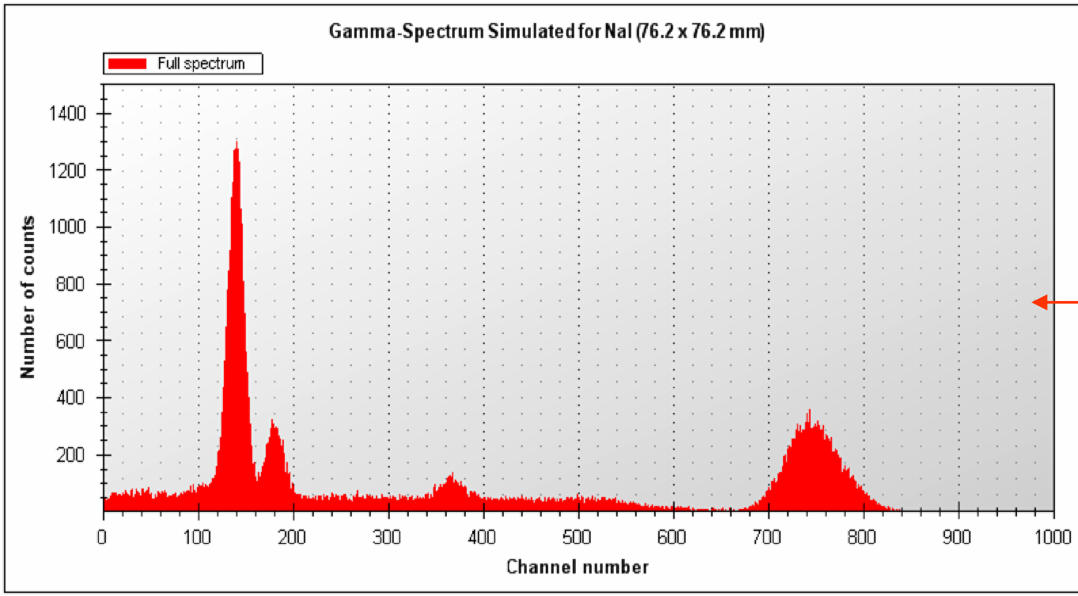
- Count rate at start
- Count rate at end
- Theoretical number of counts
- Statistical number of counts

Measurement setup | Calculation results | Options

Data displayed: Statistical number of counts

View/Save results in Text format or as IAEA-SPE spectrum.

Complete set of spectral information can be saved as a text file or as IAEA-SPE spectrum.



Right click within the graph area enables a context menu, from which one can print or download the spectrum graph

Update spectrum graph

Display: Energy scale | Spectrum continuum | Contribution of scattered photons | More graph options

Switch between channel number and energy scale; show peak, continuum and backscatter peak contributions to the full spectrum

Additional options allow to customize appearance of the graph to meet one's needs and requirements

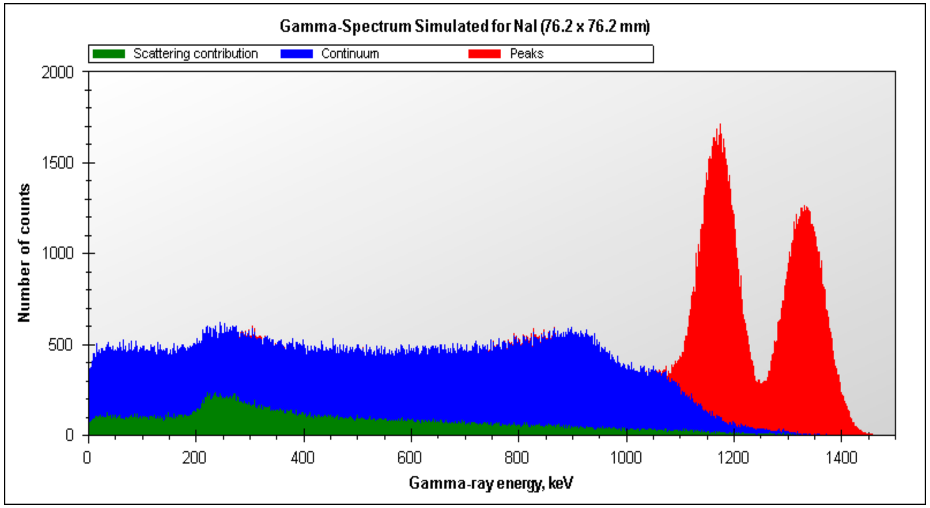
No.	Nuclide	Count rate at start, cps	Count rate at end, cps	Spectrum counts	Display
1	42 Mo 99	6.23E+01	6.22E+01	6.26E+04	☐
2	43 Tc 99	6.70E-15	6.79E-15	0.00E+00	☐
3	43 Tc 99m	2.69E+01	2.68E+01	2.70E+04	☐
	Total	**8.92E+01**	**8.90E+01**	**8.97E+04**	

Display nuclide specific contributions to the full spectrum

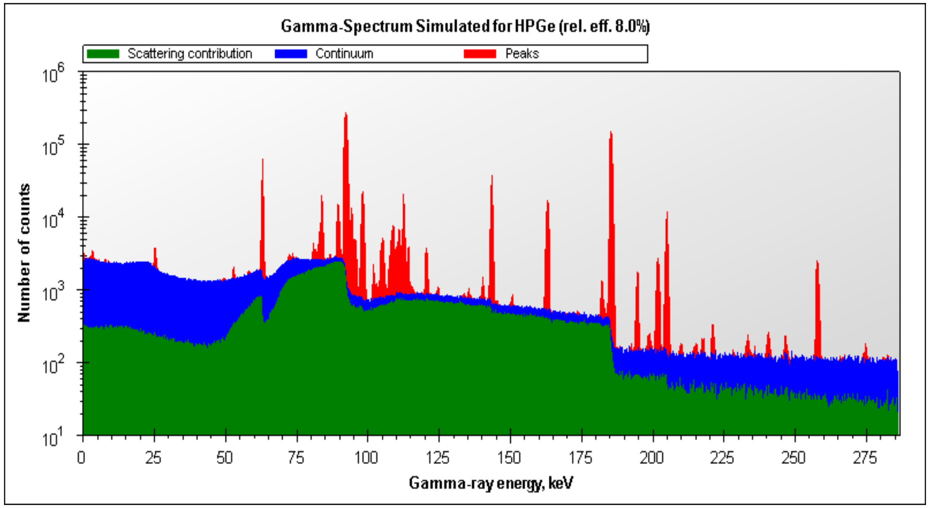
GSG in basic mode: GSG features

Displaying peak and continuum contributions:

100 kBq ^{60}Co



1 g Nat U (2 years after separation)

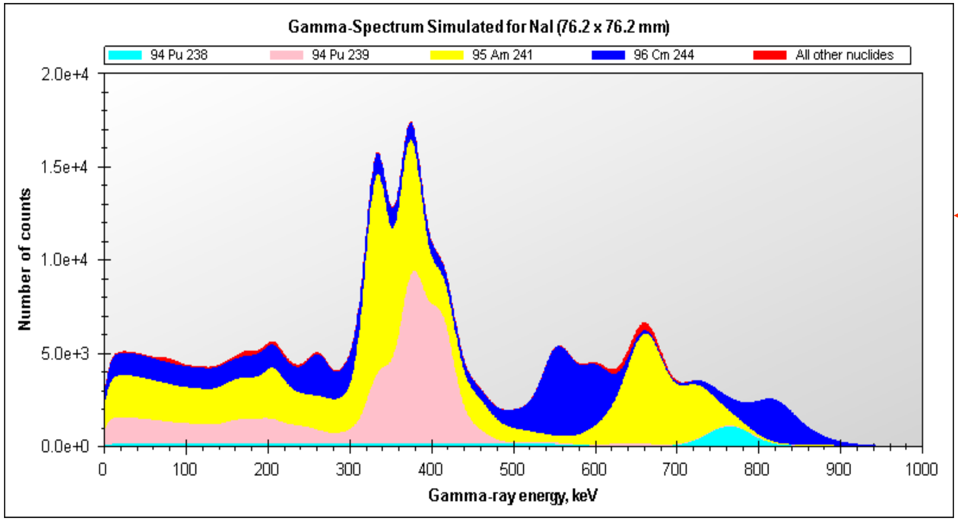


Detector - NaI (∅3″×3″)
Source-to-detector distance - 25 cm
Measurement time - 1000 s

Detector – LEGe (20 mm × 2800 mm^2)
Source-to-detector distance – 25 mm
Filter – 0.5 mm Sn
Measurement time - 10^5 s

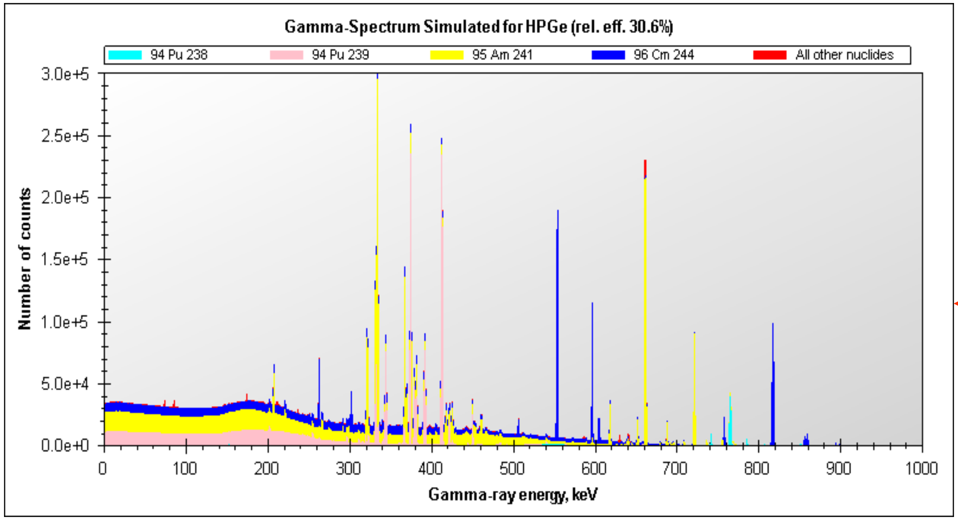
GSG in basic mode: GSG features

Displaying contributions of different nuclides:



Detector – NaI (∅3″×3″)
Source-to-detector distance – 25 cm
Filter – 5 mm Pb
Measurement time - 1000 s

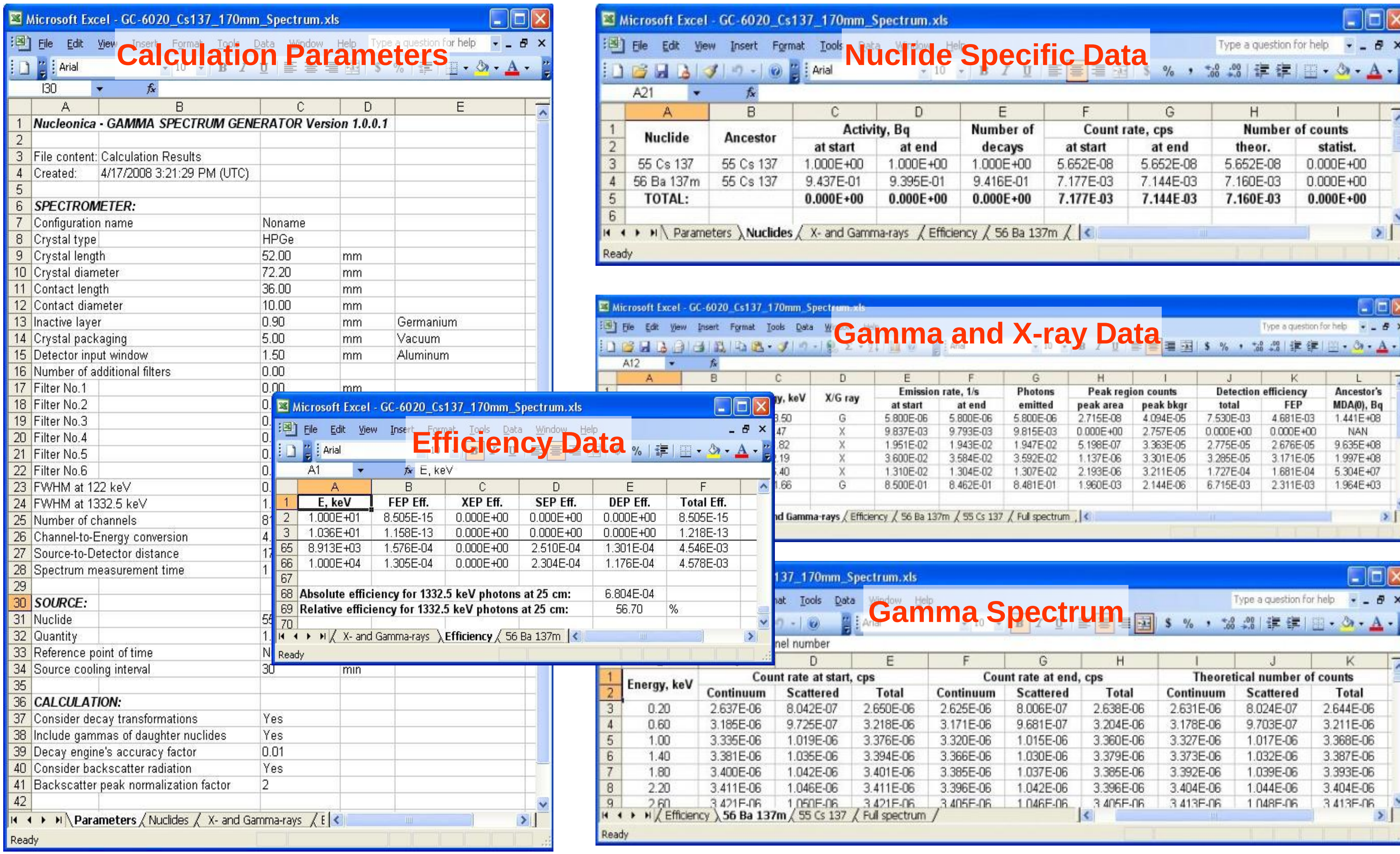
Actinides extracted from 1 kg 6-year-aged PWR spent fuel. Activity - 5.25 TBq



Detector – BEGe (30% rel. eff.)
Source-to-detector distance – 25 cm
Filter – 5 mm Pb
Measurement time - 1000 s

GSG in basic mode: GSG features

Saving calculation results in Text / Excel formats:



Calculation Parameters

	A	B	C	D	E
1	*Nucleonica - GAMMA SPECTRUM GENERATOR Version 1.0.0.1*				
2					
3	File content: Calculation Results				
4	Created: 4/17/2008 3:21:29 PM (UTC)				
5					
6	*SPECTROMETER:*				
7	Configuration name		Noname		
8	Crystal type		HPGe		
9	Crystal length		52.00	mm	
10	Crystal diameter		72.20	mm	
11	Contact length		36.00	mm	
12	Contact diameter		10.00	mm	
13	Inactive layer		0.90	mm	Germanium
14	Crystal packaging		5.00	mm	Vacuum
15	Detector input window		1.50	mm	Aluminum
16	Number of additional filters		0.00		
17	Filter No.1		0.00	mm	
18	Filter No.2		0.		
19	Filter No.3		0.		
20	Filter No.4		0.		
21	Filter No.5		0.		
22	Filter No.6		0.		
23	FWHM at 122 keV		0.		
24	FWHM at 1332.5 keV		1.		
25	Number of channels		8		
26	Channel-to-Energy conversion		4.		
27	Source-to-Detector distance		1		
28	Spectrum measurement time		1		
29					
30	*SOURCE:*				
31	Nuclide		55		
32	Quantity		1.		
33	Reference point of time		N		
34	Source cooling interval		30	min	
35					
36	*CALCULATION:*				
37	Consider decay transformations		Yes		
38	Include gammas of daughter nuclides		Yes		
39	Decay engine's accuracy factor		0.01		
40	Consider backscatter radiation		Yes		
41	Backscatter peak normalization factor		2		
42					

Parameters / Nuclides / X- and Gamma-rays

Efficiency Data

	A	B	C	D	E	F
1	E, keV	FEP Eff.	XEP Eff.	SEP Eff.	DEP Eff.	Total Eff.
2	1.000E+01	8.505E-15	0.000E+00	0.000E+00	0.000E+00	8.505E-15
3	1.036E+01	1.158E-13	0.000E+00	0.000E+00	0.000E+00	1.218E-13
65	8.913E+03	1.576E-04	0.000E+00	2.510E-04	1.301E-04	4.546E-03
66	1.000E+04	1.305E-04	0.000E+00	2.304E-04	1.176E-04	4.578E-03
67						
68	Absolute efficiency for 1332.5 keV photons at 25 cm:				6.804E-04	
69	Relative efficiency for 1332.5 keV photons at 25 cm:				56.70	%
70						

X- and Gamma-rays / Efficiency / 56 Ba 137m

Nuclide Specific Data

	A	B	C	D	E	F	G	H	I
1	Nuclide	Ancestor	Activity, Bq		Number of	Count rate, cps		Number of counts	
2			at start	at end	decays	at start	at end	theor.	statist.
3	55 Cs 137	55 Cs 137	1.000E+00	1.000E+00	1.000E+00	5.652E-08	5.652E-08	5.652E-08	0.000E+00
4	56 Ba 137m	55 Cs 137	9.437E-01	9.395E-01	9.416E-01	7.177E-03	7.144E-03	7.160E-03	0.000E+00
5	TOTAL:		0.000E+00	0.000E+00	0.000E+00	7.177E-03	7.144E-03	7.160E-03	0.000E+00
6									

Parameters / Nuclides / X- and Gamma-rays / Efficiency / 56 Ba 137m

Gamma and X-ray Data

C	D	E	F	G	H	I	J	K	L
gy, keV	X/G ray	Emission rate, 1/s		Photons	Peak region counts		Detection efficiency		Ancestor's
		at start	at end	emitted	peak area	peak bkgr	total	FEP	MDA(0), Bq
3.50	G	5.800E-06	5.800E-06	5.800E-06	2.715E-08	4.094E-05	7.530E-03	4.681E-03	1.441E+08
.47	X	9.837E-03	9.793E-03	9.815E-03	0.000E+00	2.757E-05	0.000E+00	0.000E+00	NAN
.82	X	1.951E-02	1.943E-02	1.947E-02	5.198E-07	3.363E-05	2.775E-05	2.676E-05	9.635E+08
.19	X	3.600E-02	3.584E-02	3.592E-02	1.137E-06	3.301E-05	3.285E-05	3.171E-05	1.997E+08
.40	X	1.310E-02	1.304E-02	1.307E-02	2.193E-06	3.211E-05	1.727E-04	1.681E-04	5.304E+07
1.66	G	8.500E-01	8.462E-01	8.481E-01	1.960E-03	2.144E-06	6.715E-03	2.311E-03	1.964E+03

nd Gamma-rays / Efficiency / 56 Ba 137m / 55 Cs 137 / Full spectrum

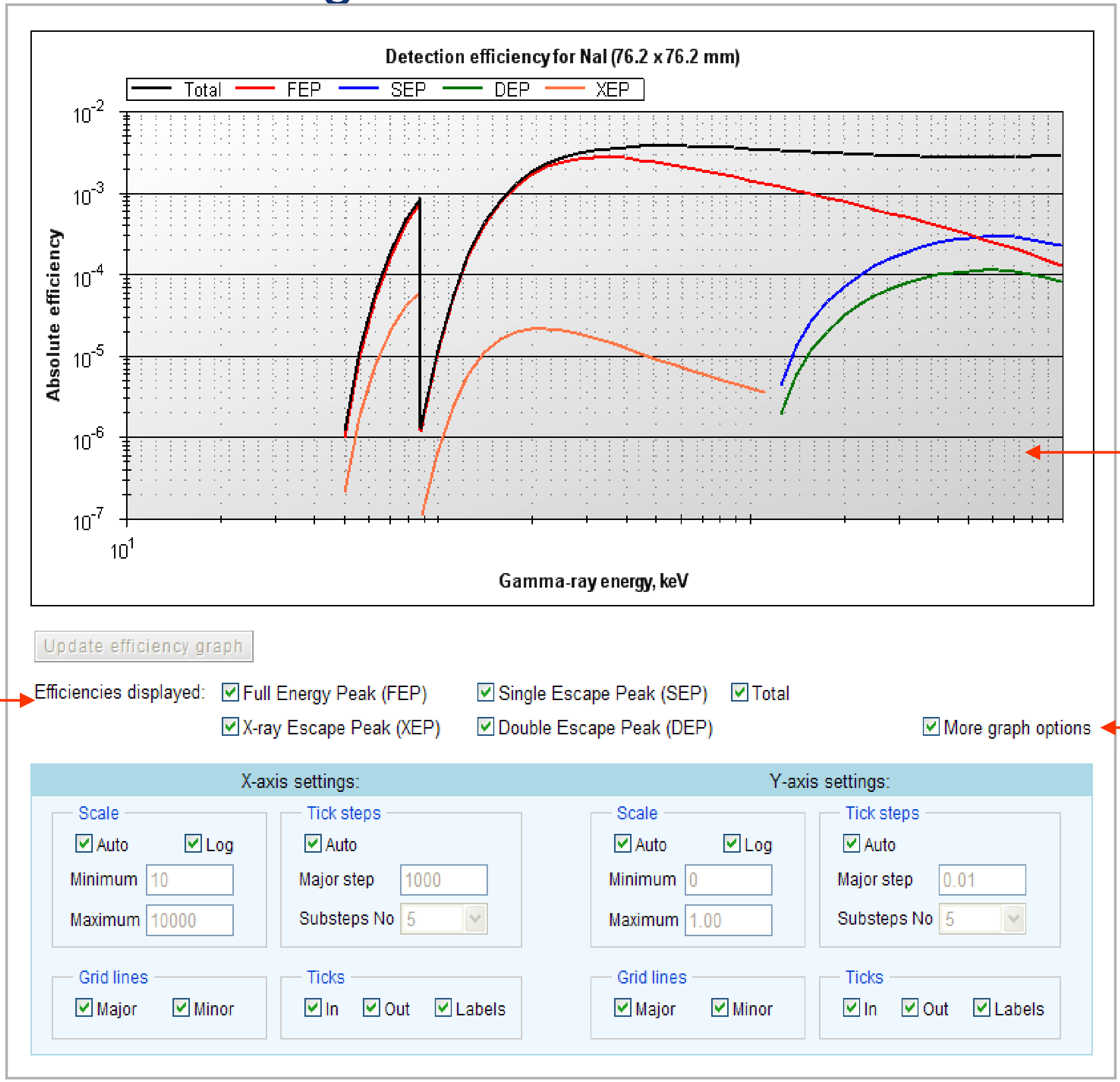
Gamma Spectrum

	Energy, keV	Count rate at start, cps			Count rate at end, cps			Theoretical number of counts		
2		Continuum	Scattered	Total	Continuum	Scattered	Total	Continuum	Scattered	Total
3	0.20	2.637E-06	8.042E-07	2.650E-06	2.625E-06	8.006E-07	2.638E-06	2.631E-06	8.024E-07	2.644E-06
4	0.60	3.185E-06	9.725E-07	3.218E-06	3.171E-06	9.681E-07	3.204E-06	3.178E-06	9.703E-07	3.211E-06
5	1.00	3.335E-06	1.019E-06	3.376E-06	3.320E-06	1.015E-06	3.360E-06	3.327E-06	1.017E-06	3.368E-06
6	1.40	3.381E-06	1.035E-06	3.394E-06	3.366E-06	1.030E-06	3.379E-06	3.373E-06	1.032E-06	3.387E-06
7	1.80	3.400E-06	1.042E-06	3.401E-06	3.385E-06	1.037E-06	3.385E-06	3.392E-06	1.039E-06	3.393E-06
8	2.20	3.411E-06	1.046E-06	3.411E-06	3.396E-06	1.042E-06	3.396E-06	3.404E-06	1.044E-06	3.404E-06
9	2.60	3.421E-06	1.050E-06	3.421E-06	3.405E-06	1.046E-06	3.405E-06	3.413E-06	1.048E-06	3.413E-06

Efficiency / 56 Ba 137m / 55 Cs 137 / Full spectrum

GSG in basic mode: GSG features

Plotting detection efficiencies:



Right click within the graph area enables a context menu, from which one can print or download the efficiency graph

Select efficiency data to be displayed on the graph

Additional options allow to tailor the efficiency graph to one’s needs and requirements

GSG in basic mode: Experimental validation (HPGe)

Experimental validation with 60% HPGe coaxial detector (INR, Kiev)

Detector: coaxial HPGe (Canberra)

- Relative efficiency: 61.8%
- Crystal dimensions: ∅74 mm × 53 mm
- Rear contact: ∅10 mm × 36 mm
- Inactive Ge: 0.7 mm
- Crystal end cap: 1.5 mm Al
- End cap to crystal gap: 5 mm
- FWHM: 1.75 keV at 1.33 MeV

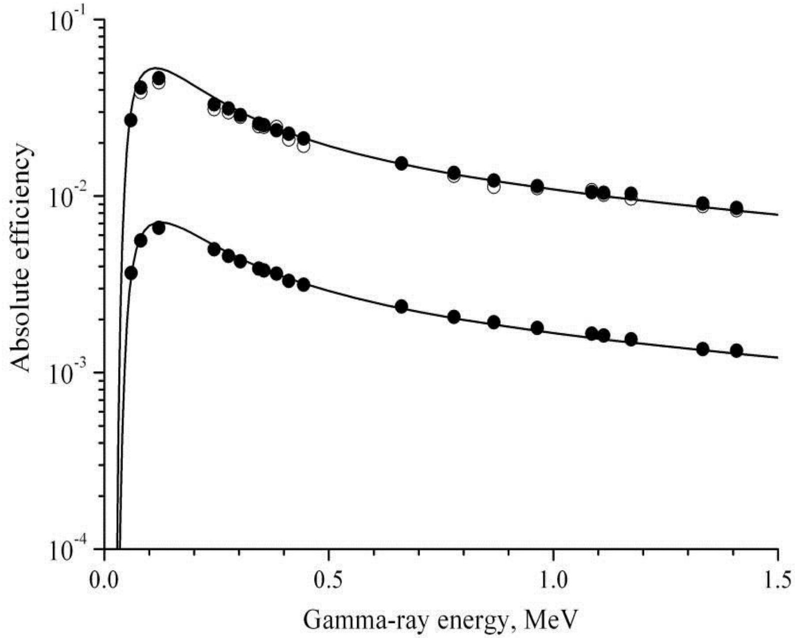
Sources: Thin Spectroscopic Reference Gamma-Sources (SOSGI)

- ^{137}Cs, ^{60}Co, ^{152}Eu

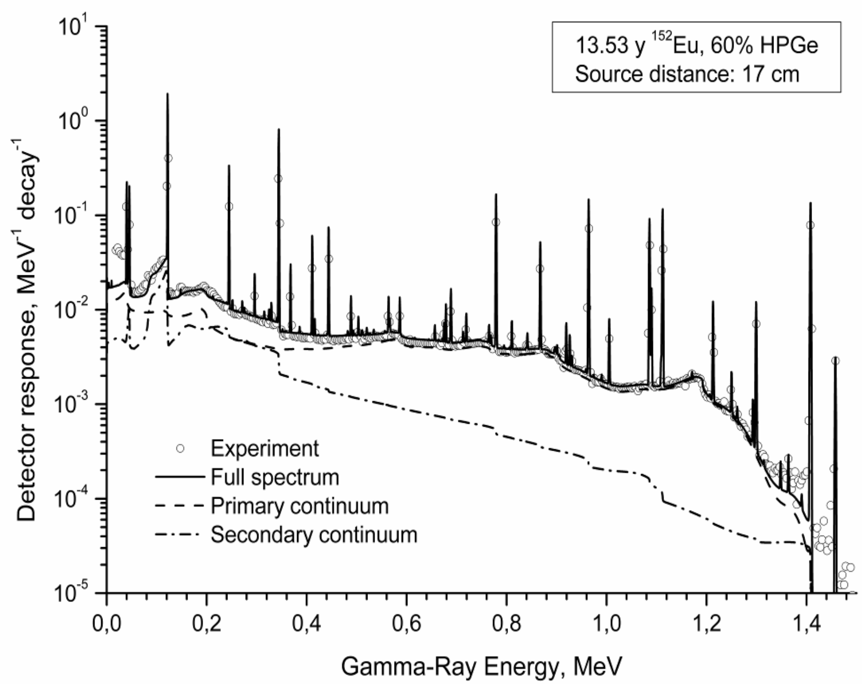
Measurement conditions: Center of experimental room

GSG in basic mode: Experimental validation (HPGe)

Results of the experimental validation with 60% HPGe coaxial detector



Full Energy Peak efficiency as a function of the photon energy: circles – experimental values, curve – calculated. Two sets of data refer to the source location at 5 cm and 17 cm distances from the detector end cap.



Calculated (curve) and experimental (circles) detector responses for ^{152}Eu source at 17 cm distance from the detector end cap.

GSG in basic mode: Experimental validation (NaI)

REVISED EDITION OF REPORT IDO - 16880 - 1
ORIGINAL ISSUED: AUGUST 1964
REV. ELECTRONIC UPDATE:: FEBRUARY 1997

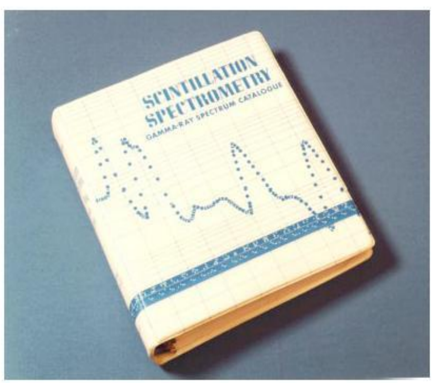
SCINTILLATION SPECTROMETRY

GAMMA-RAY SPECTRUM CATALOGUE

NEW VERSION OF 2ND EDITION
COMPILATION OF GAMMA-RAY SPECTRA
AND RELATED NUDCLEAR DECAY DATA
VOLUME 1 OF 2

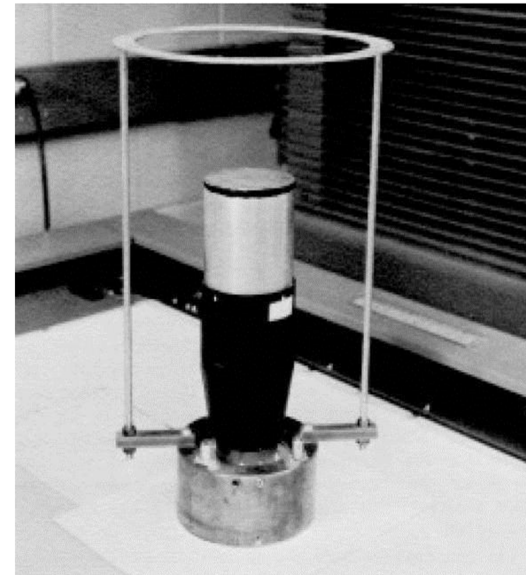
BY

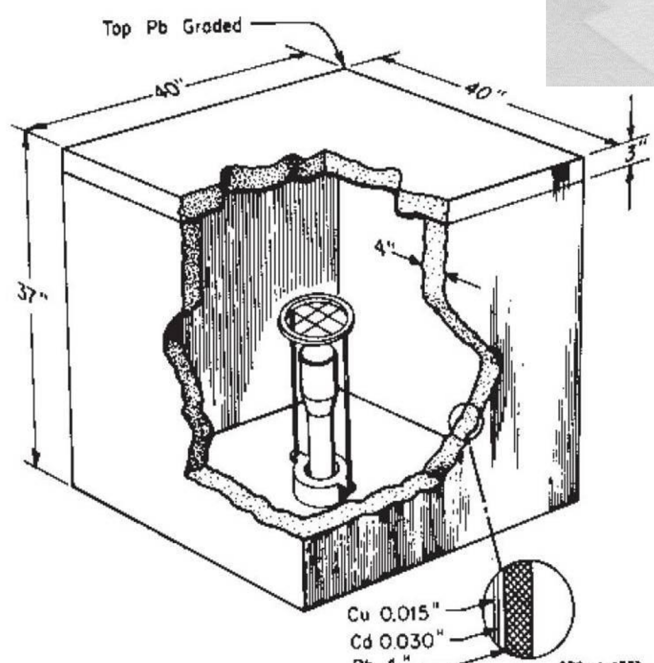
R. L. HEATH



-RAY SPECTROMETRY CENTER
Idaho National Engineering & Environmental Laboratory

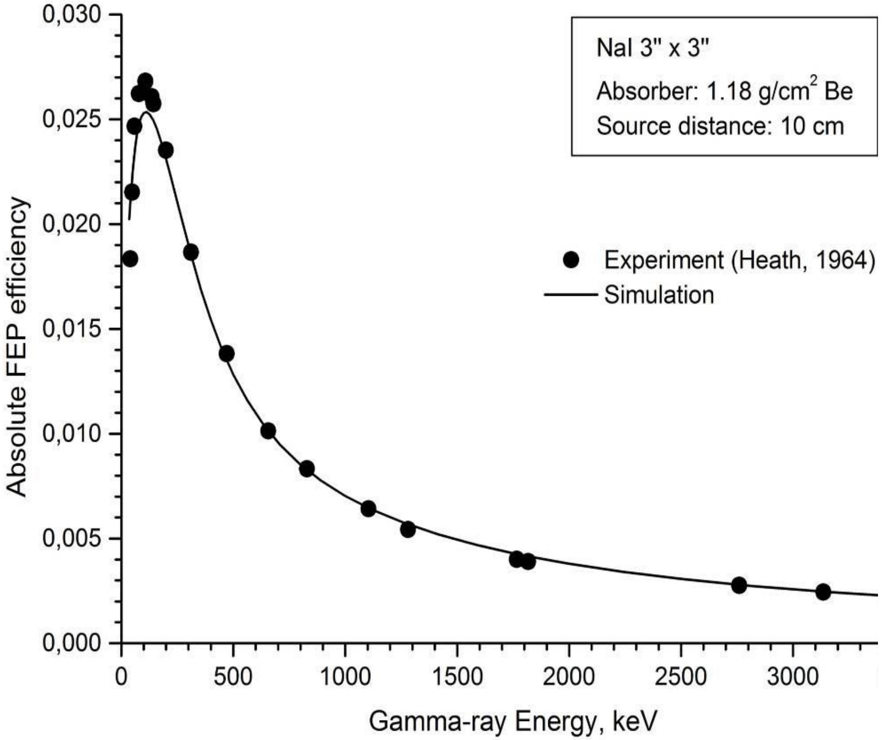
Detector:
3″ × 3″ NaI scintillation detector

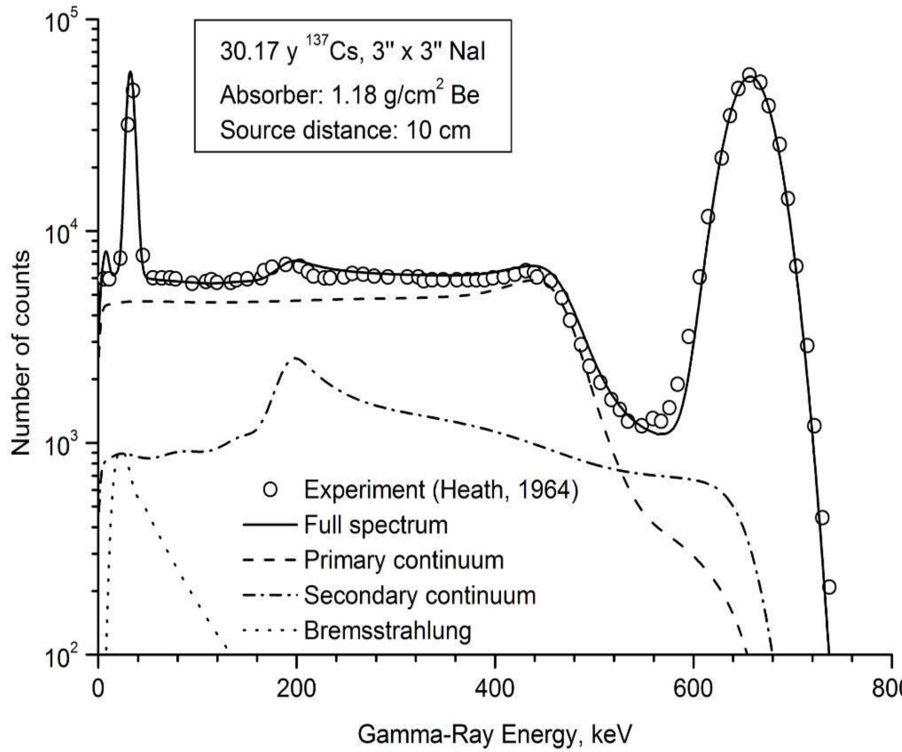




GSG in basic mode: Experimental validation (NaI)

Results of the experimental validation with 3″ × 3″ NaI scintillation detector



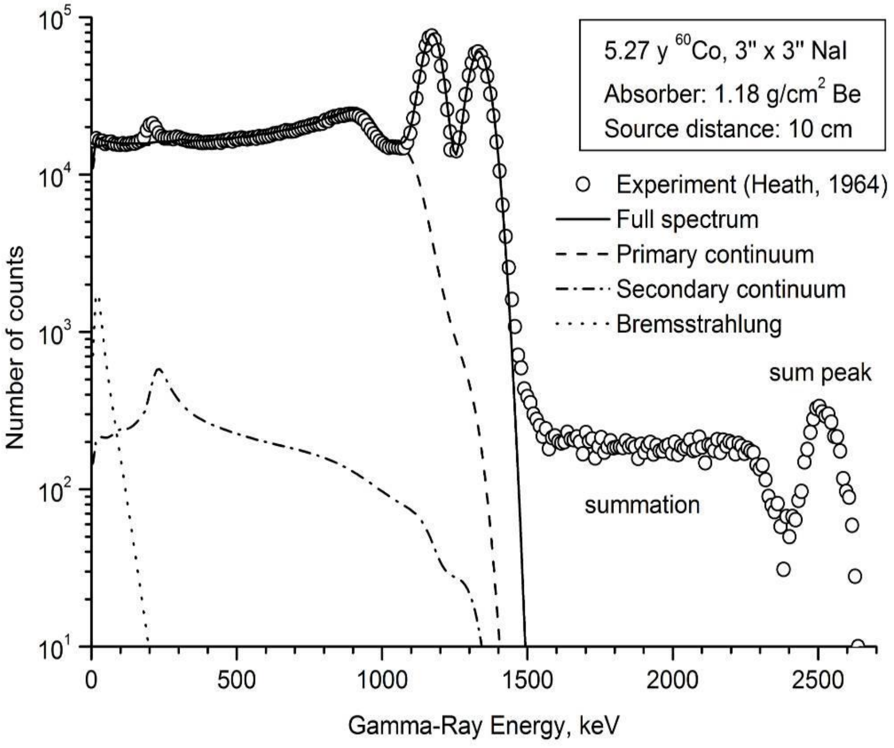


The simulated vs. experimental *FEP* efficiencies for a NaI 3″ × 3″ detector.

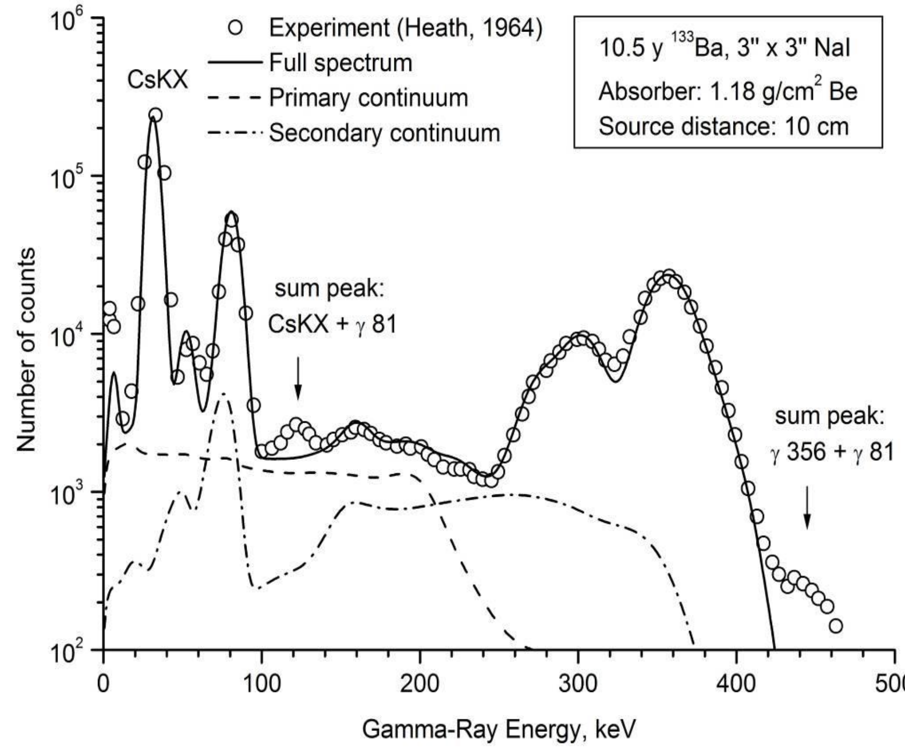
The experimental and simulated spectra for ^{137}Cs and a NaI 3″ × 3″ detector .

GSG in basic mode: Experimental validation (NaI)

Results of the experimental validation with 3″ × 3″ NaI scintillation detector



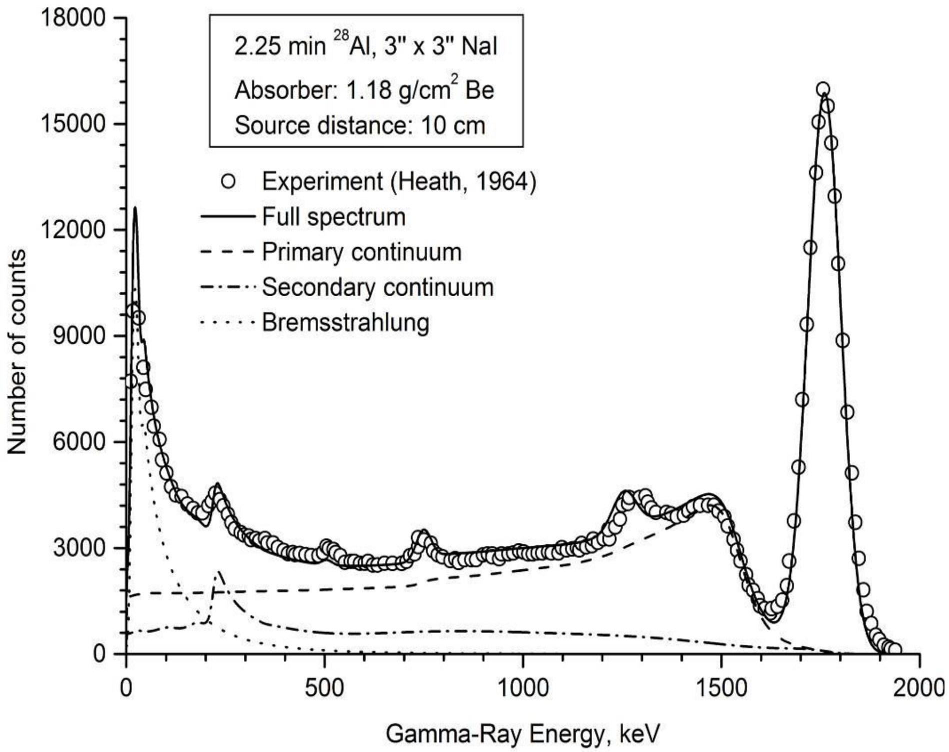
The experimental and simulated spectra for ^{60}Co and a NaI 3″ × 3″ detector.



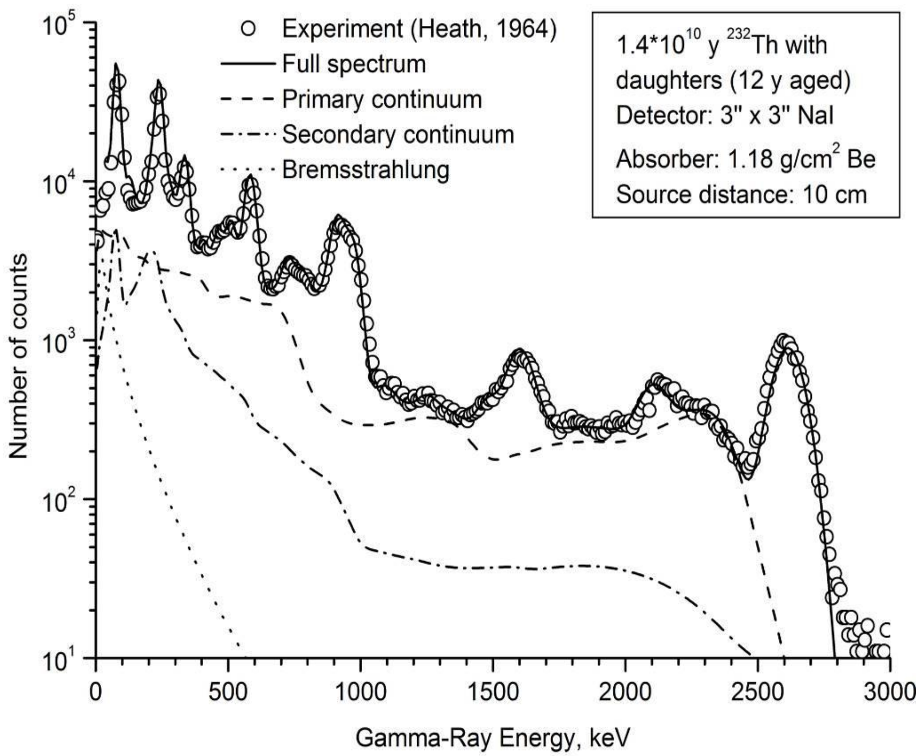
The experimental and simulated spectra for ^{133}Ba and a NaI 3″ × 3″ detector.

GSG in basic mode: Experimental validation (NaI)

Results of the experimental validation with 3″ × 3″ NaI scintillation detector

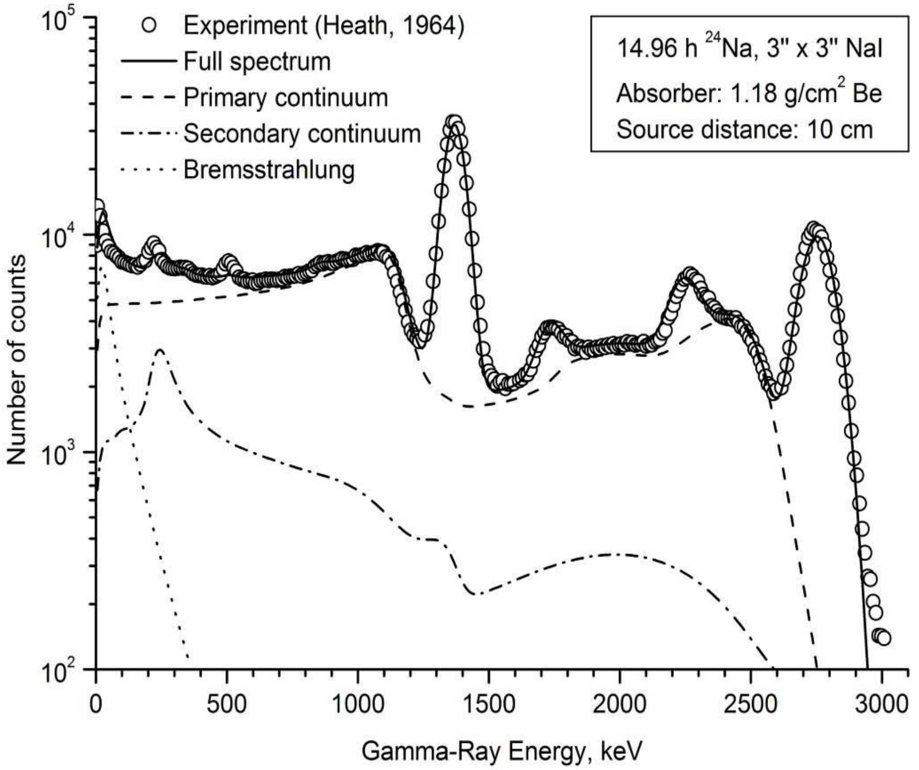


The experimental and simulated spectra for ^{28}Al and a NaI 3″ × 3″ detector .

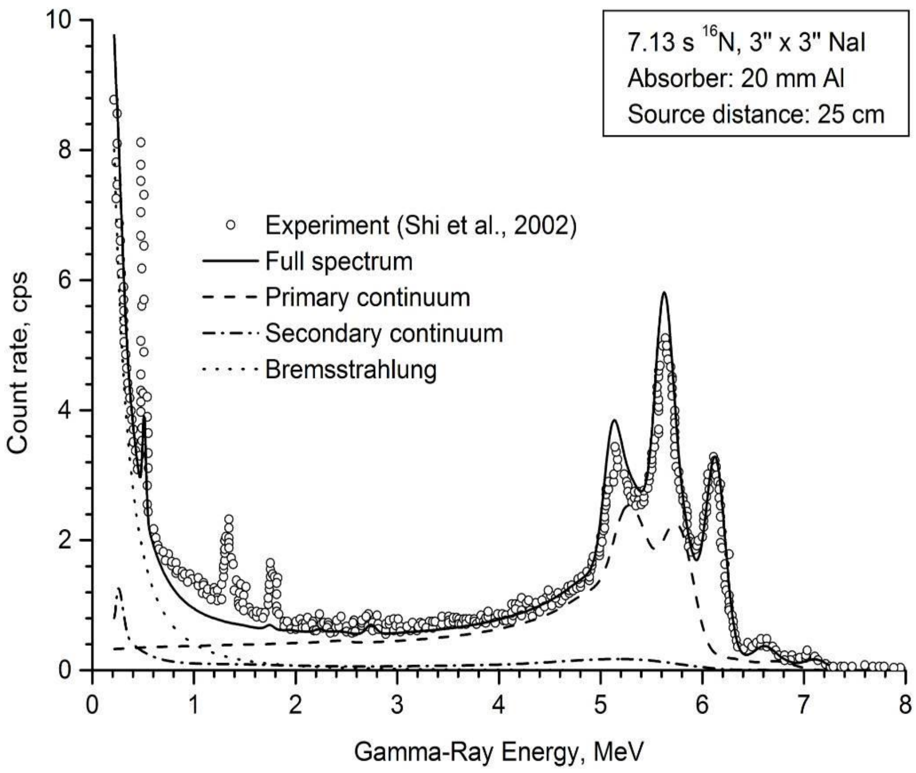


The experimental and simulated spectra for a 12 year old ^{232}Th source and a NaI 3″ × 3″ detector.

Results of the experimental validation with 3″ × 3″ NaI scintillation detector



The experimental and simulated spectra for ^{24}Na and a NaI 3″ × 3″ detector.

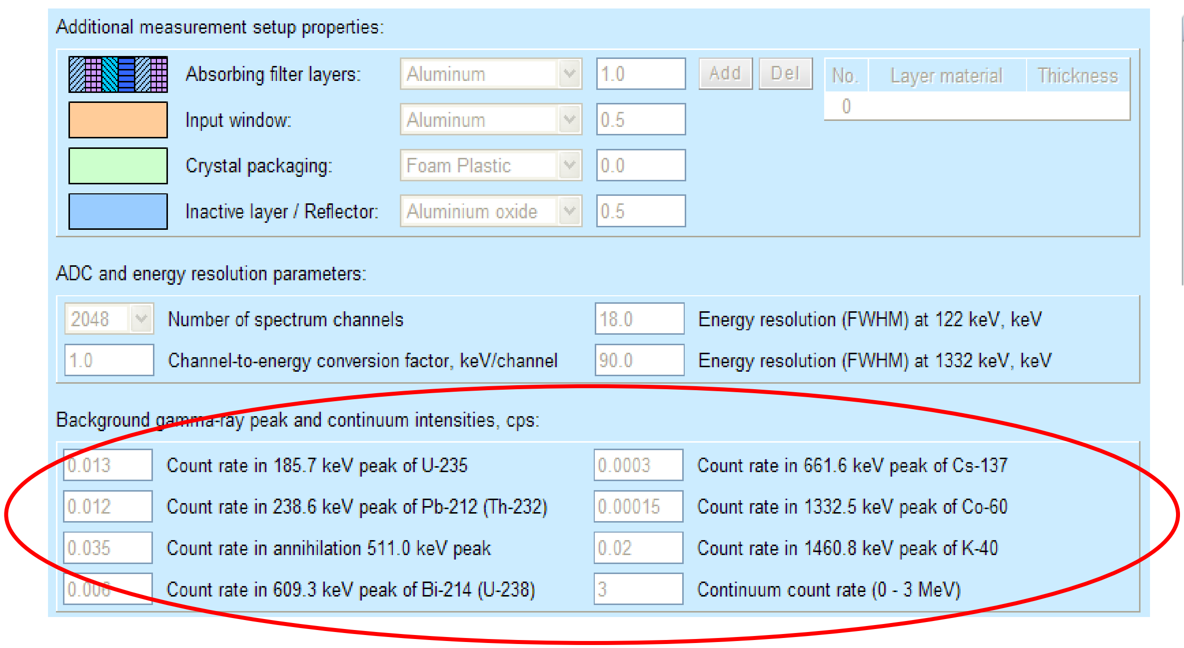


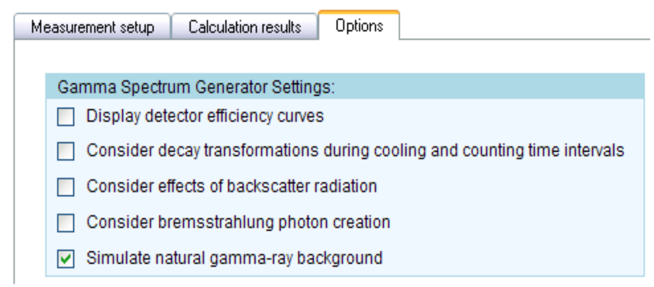
The experimental and simulated spectra for ^{16}N and a NaI 3″ × 3″ detector.

GSG-PRO: Additional modeling features

1. Modeling of a contribution from naturally occurring radionuclides (natural gamma radiation background)

Additional interface features:



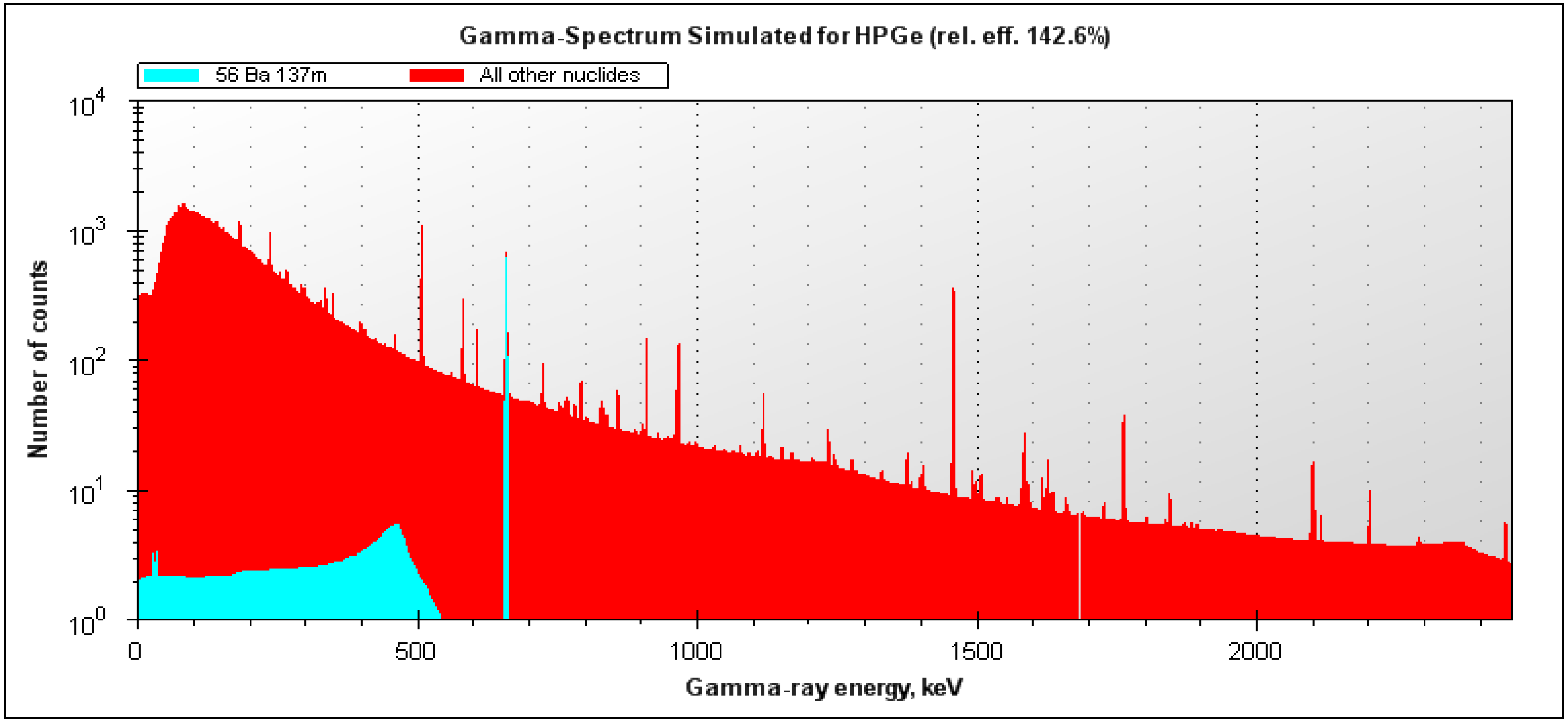


A respective option has to be selected on „Options“ tab to enable the background simulation

GSG-PRO: Additional modeling features

Example: low-activity / low-background measurements

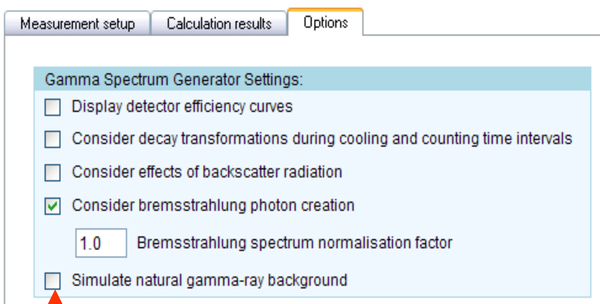
Inclusion of the background gammas results in a more realistic spectrum shape and MDA values, especially in low-activity measurements



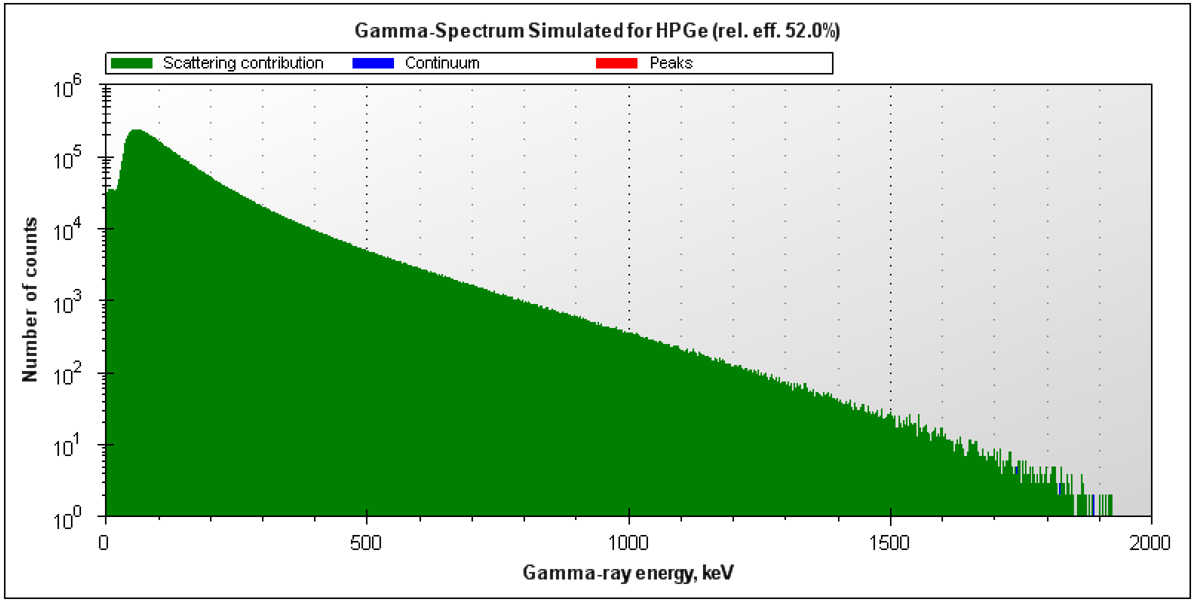
- A spectrum simulated for a 10 Bq ^{137}Cs source at the 10 mm distance from a 150% HPGe detector with natural background contribution included

GSG-PRO: Additional modeling features

2. Bremsstrahlung modeling option is available for beta-emitting nuclides:



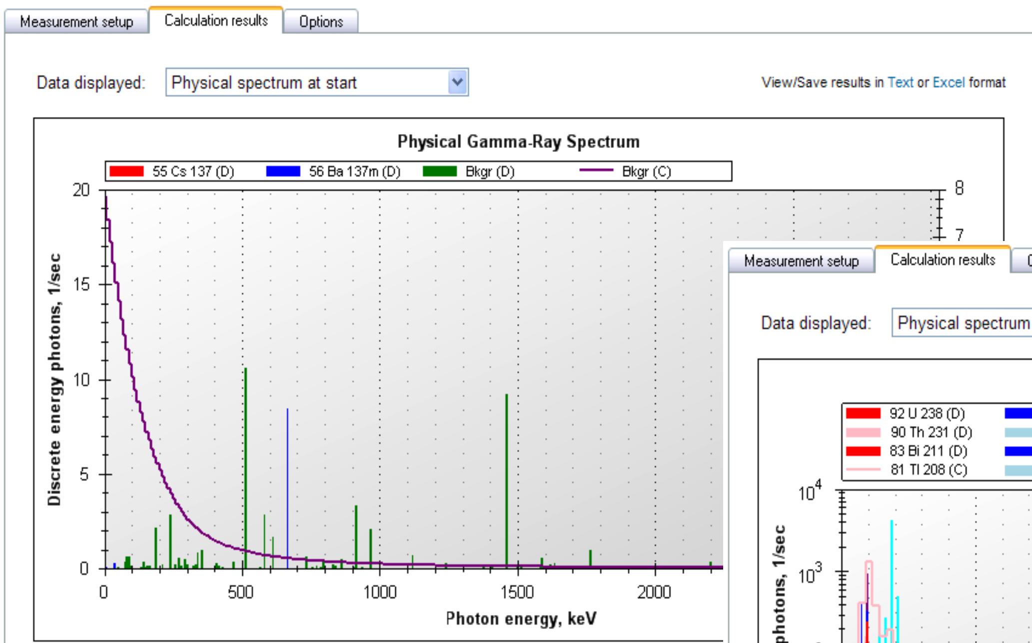
A respective option must be selected on „Options“ tab to enable the bremsstrahlung simulation.



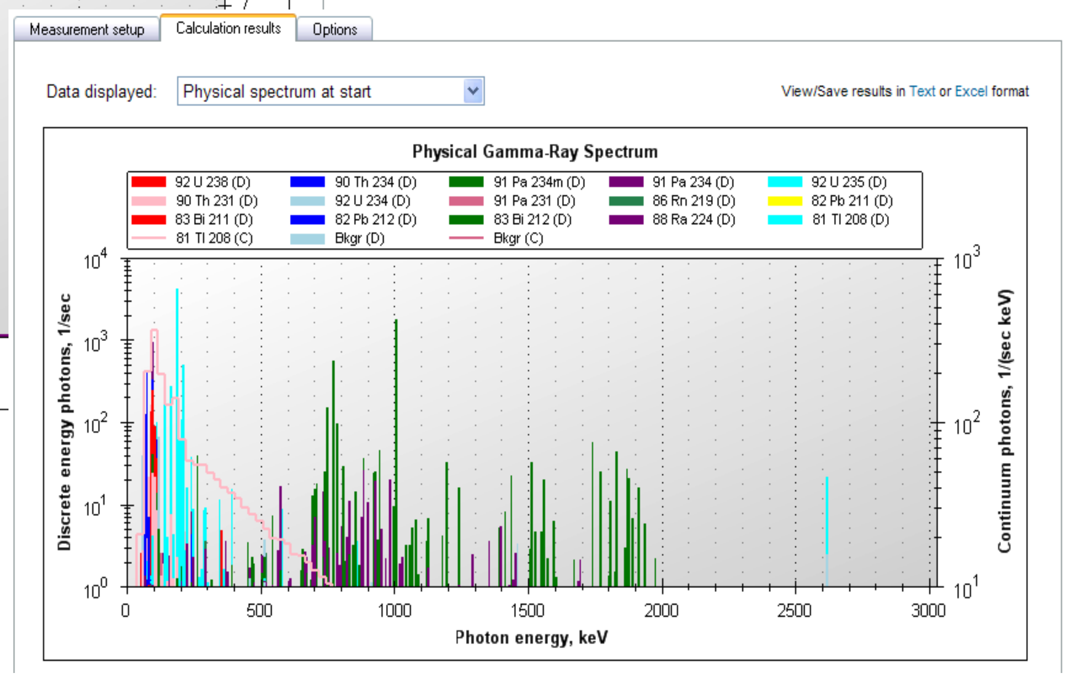
- A gamma-spectrum simulated for the 10 MBq ^{90}Sr-^{90}Y source and a 50% HPGe coaxial detector

GSG-PRO: Additional modeling features

3. Physical photon spectrum visualization



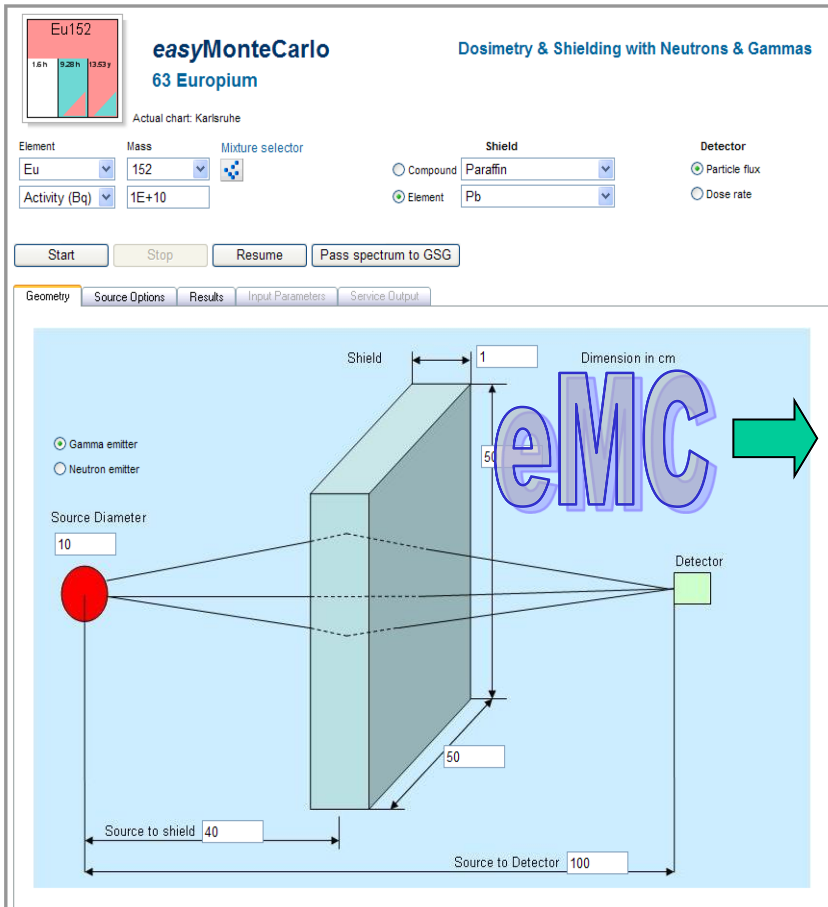
^{137}Cs source and natural background photons



4.46% Uranium source and natural background photons

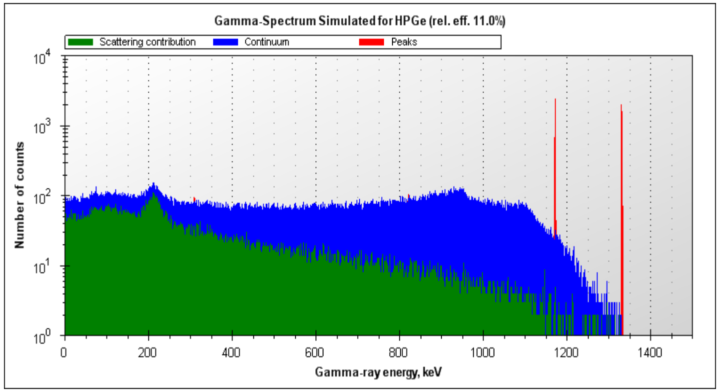
GSG-PRO: Additional modeling features

4. Modeling spectra from voluminous and heavily shielded sources using a coupled eMC (easy Monte Carlo) – GSG-PRO simulation approach:

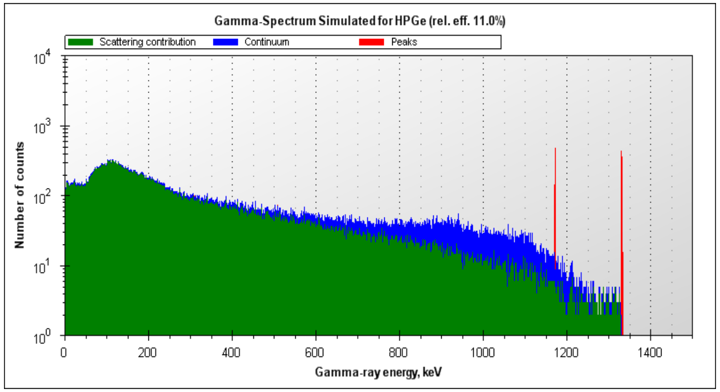


eMC → GSG

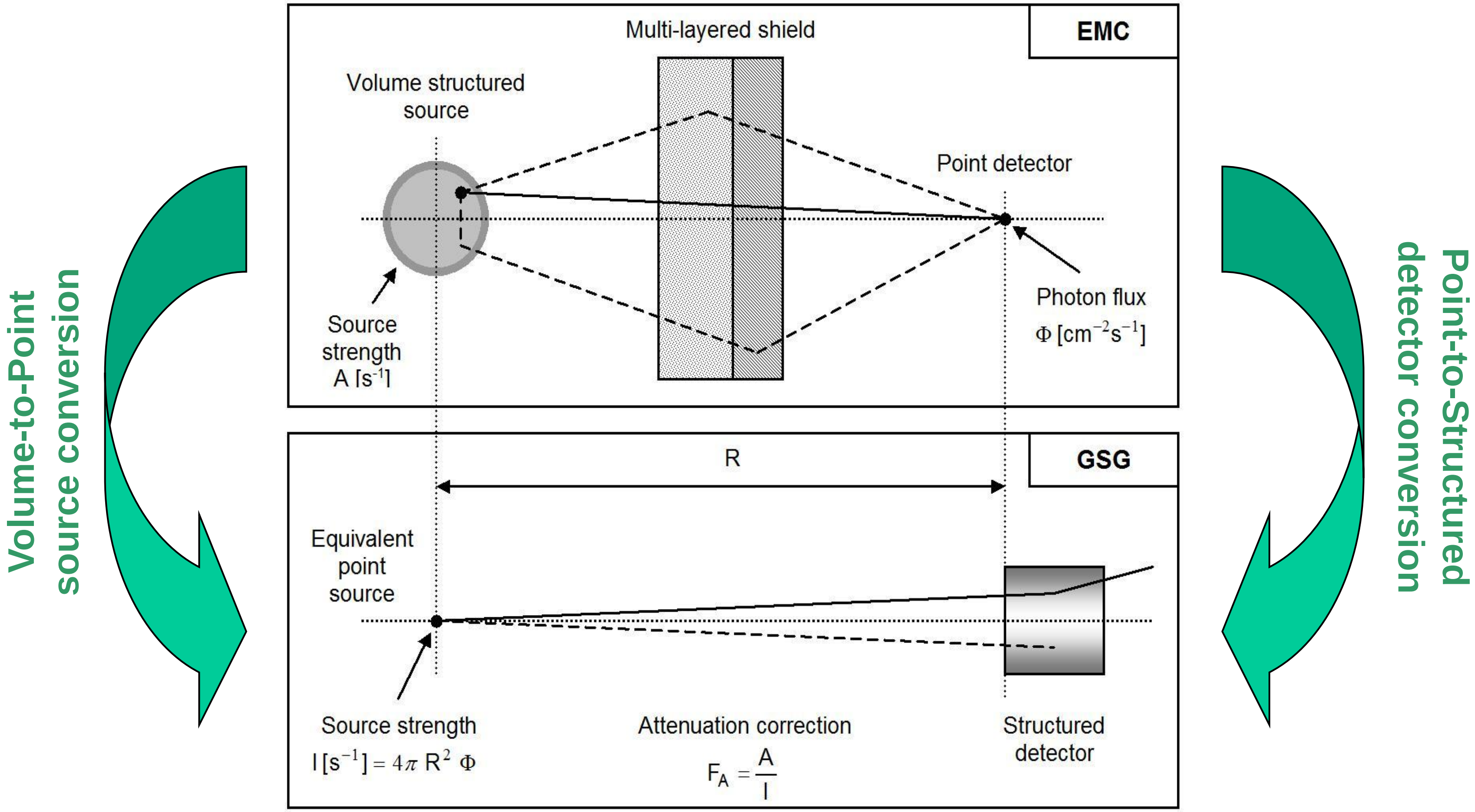
Unshielded ^{60}Co:



^{60}Co behind 12 cm Al shield:



Coupled eMC / GSG-PRO calculations for voluminous & shielded sources:

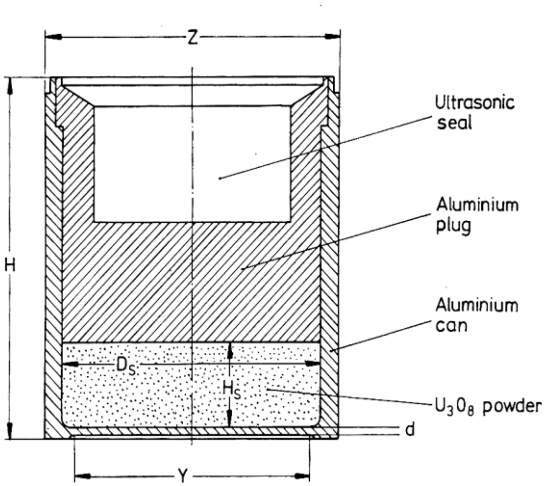


GSG-PRO: Example of experimental validation

CBNM-446 Uranium:

Separation date: 1979
U_3O_8, 200 g, 3.3 g/cm^3
Capsule: ∅ 8 × 9 cm
Sample: ∅ 7 × 1.58 cm
Al window: 0.2 cm

^{232}U – 4.1 ppt
^{234}U – 0.0359 wt %
^{235}U – 4.4623 wt %
^{236}U – 0.0068 wt %
^{238}U – 95.495 wt %



Experimental room: L × W × H = 3.3 × 3.8 × 3.5 m^3.
Shields (20 × 20 cm^2): Pb (2 cm) and Al (3 cm, 12 cm).
Detector: 10% Ortec Detective, HPGe ∅50 × 30 mm.
Shield to detector: 10 cm.
Source to shield: 0 cm.
Unshielded source: at 10 cm distance.

Nuclide	Activity	Nuclide	Activity
^{234}U	14.1 MBq	^{219}Rn	128 Bq
^{238}U	2.02 MBq	^{211}Pb	128 Bq
^{234m}Pa	2.02 MBq	^{211}Bi	128 Bq
^{234}Pa	3.03 kBq	^{212}Pb	438 Bq
^{234}Th	2.02 MBq	^{212}Bi	438 Bq
^{235}U	607 kBq	^{224}Ra	438 Bq
^{231}Th	607 kBq	^{208}Tl	157 Bq
^{231}Pa	372 kBq	**Total**	**21.4 MBq**

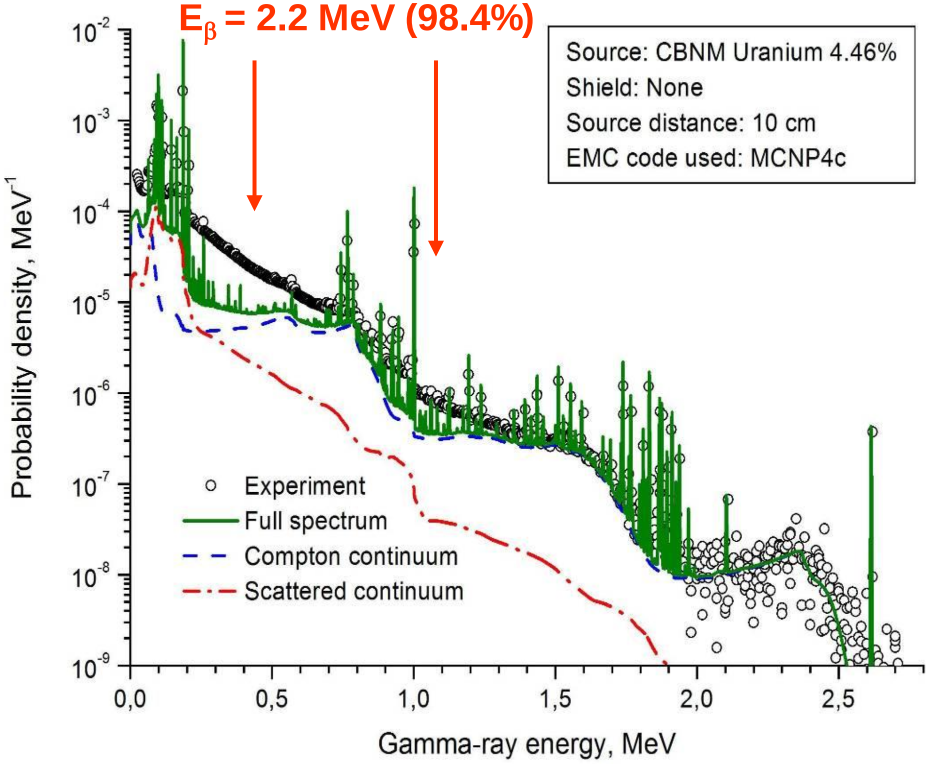
GSG-PRO: Example of experimental validation

Unshielded CBNM-446

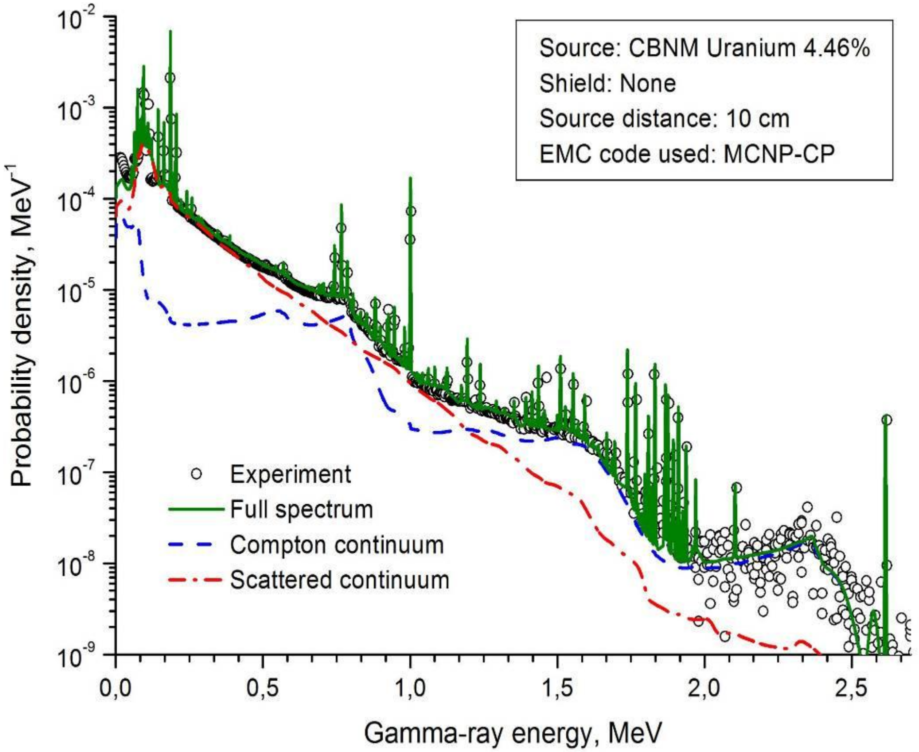
Without bremsstrahlung

^{234m}Pa

E_{β} = 2.2 MeV (98.4%)



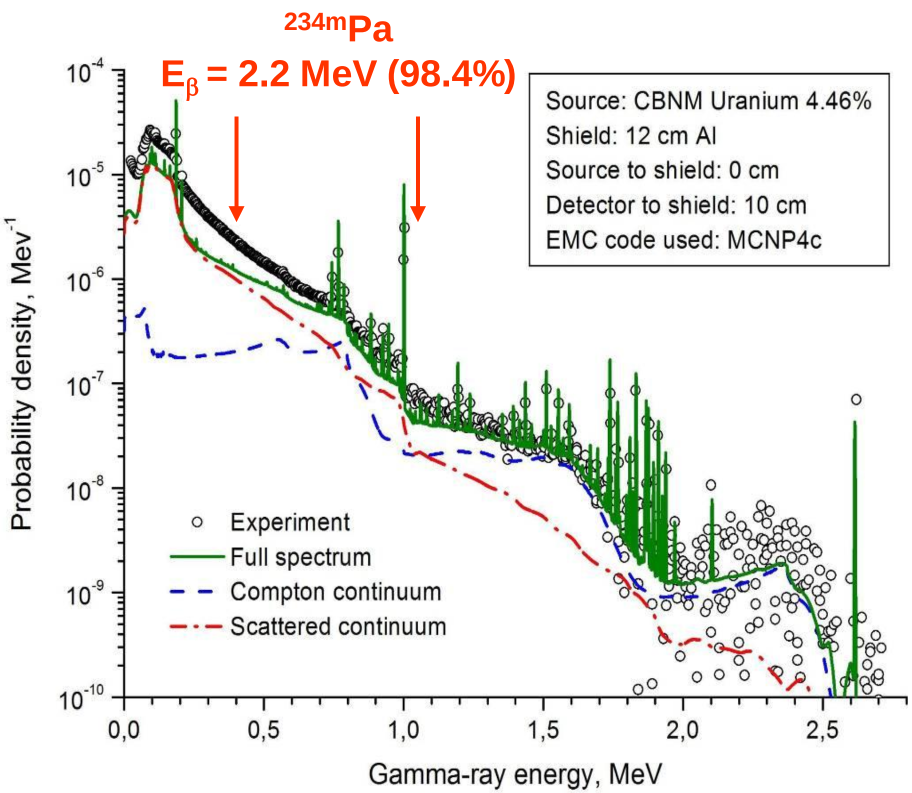
With bremsstrahlung



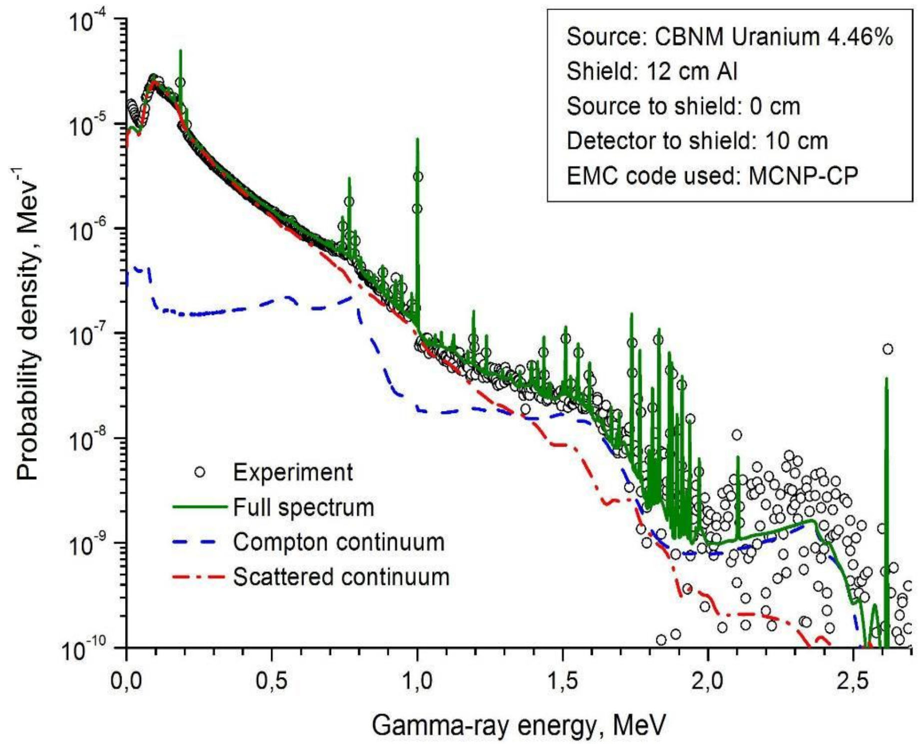
GSG-PRO: Example of experimental validation

CBNM-446 shielded with 12 cm Al

Without bremsstrahlung



With bremsstrahlung



GSG: A simple application example

TACIS: "Supply contract for the mobile laboratory and a transportable analytical instruments and equipment to be used for performing specific on-site actions needed in response to illicit trafficking incidents"

Technical specifications for
„Gamma radiation search and dose rate measurement instrument"

Detection sensitivity:

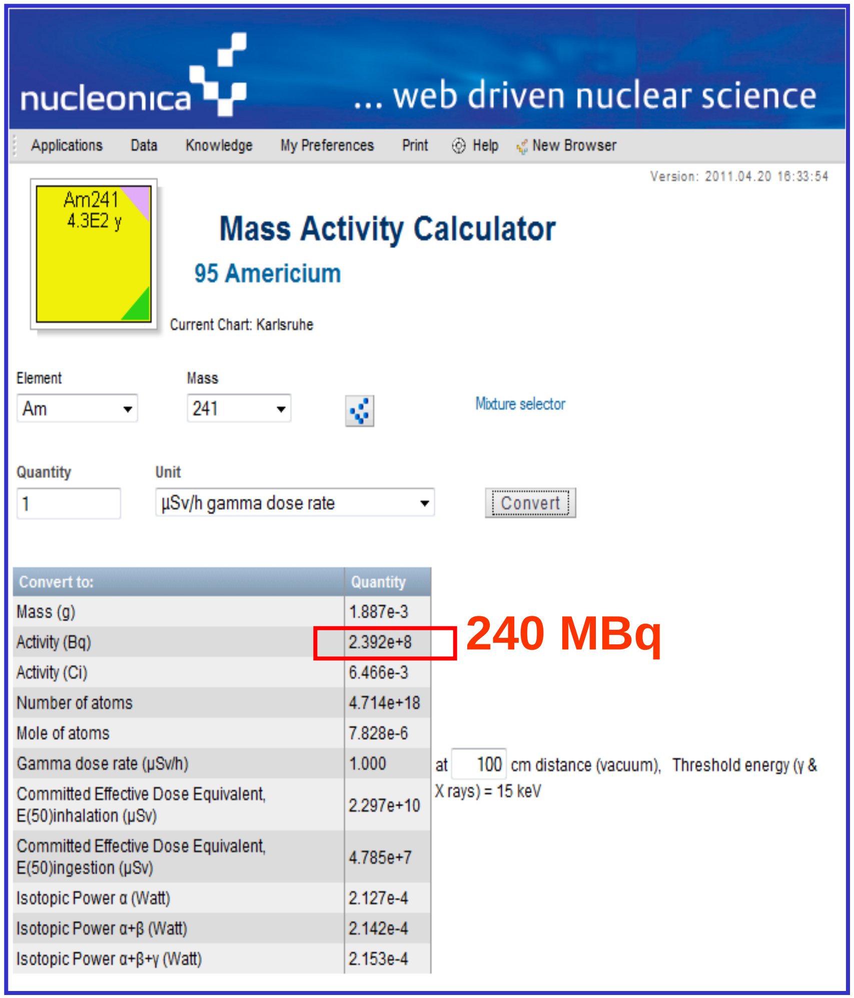
$\geq$ 10000 cps/(µSv/h) for ^{241}Am
$\geq$ 1500 cps/(µSv/h) for ^{137}Cs
$\geq$ 1000 cps/(µSv/h) for ^{60}Co
$\geq$2500 cps/(µSv/h) for natural radiation background

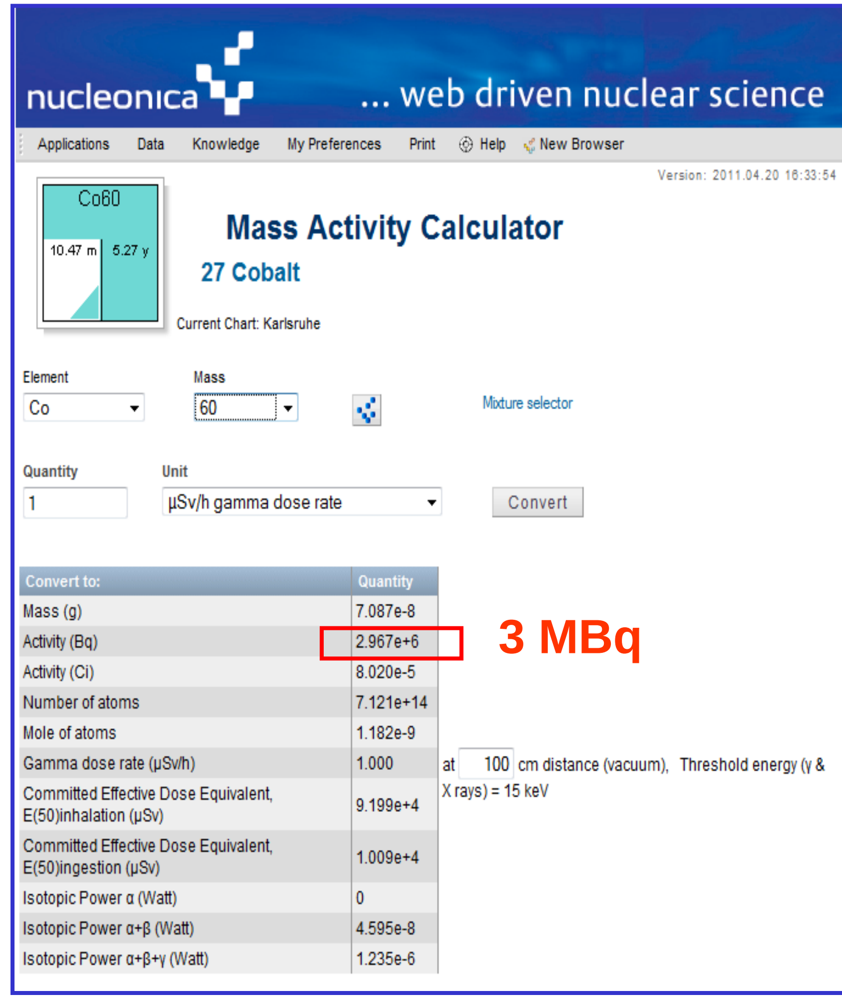
Request from a tenderer:

"We would like to review the requirement for performance. We believe that there is a mistake in the number marked in red. The highest sensitivity should be for ^{60}Co and lowest for ^{241}Am".

GSG: A simple application example

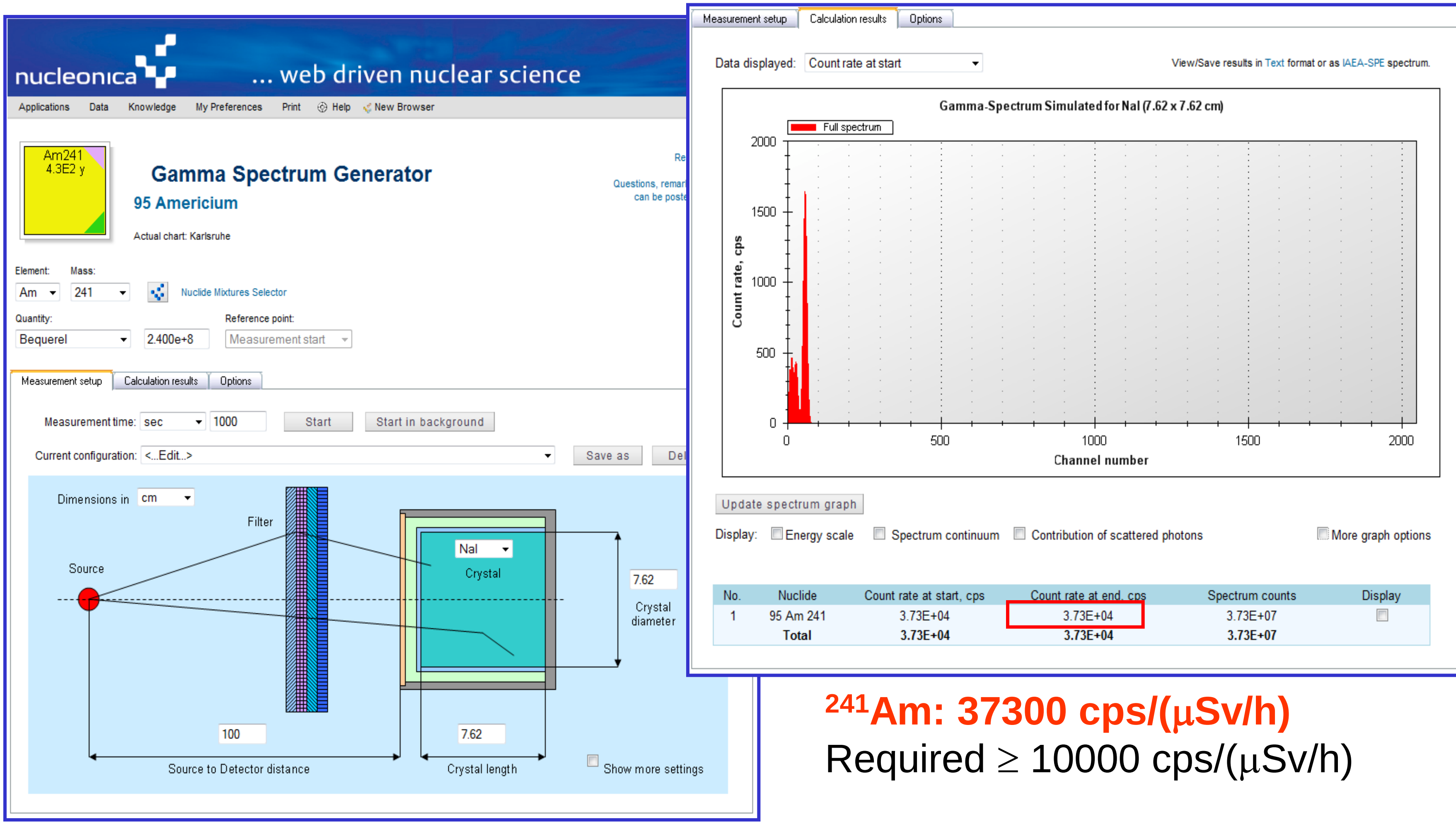
Step 1: Using Nucleonica's Mass Activity Calculator, evaluate nuclide activities that produce the dose rate of 1 μSv/h at 1 m distance:





GSG: A simple application example

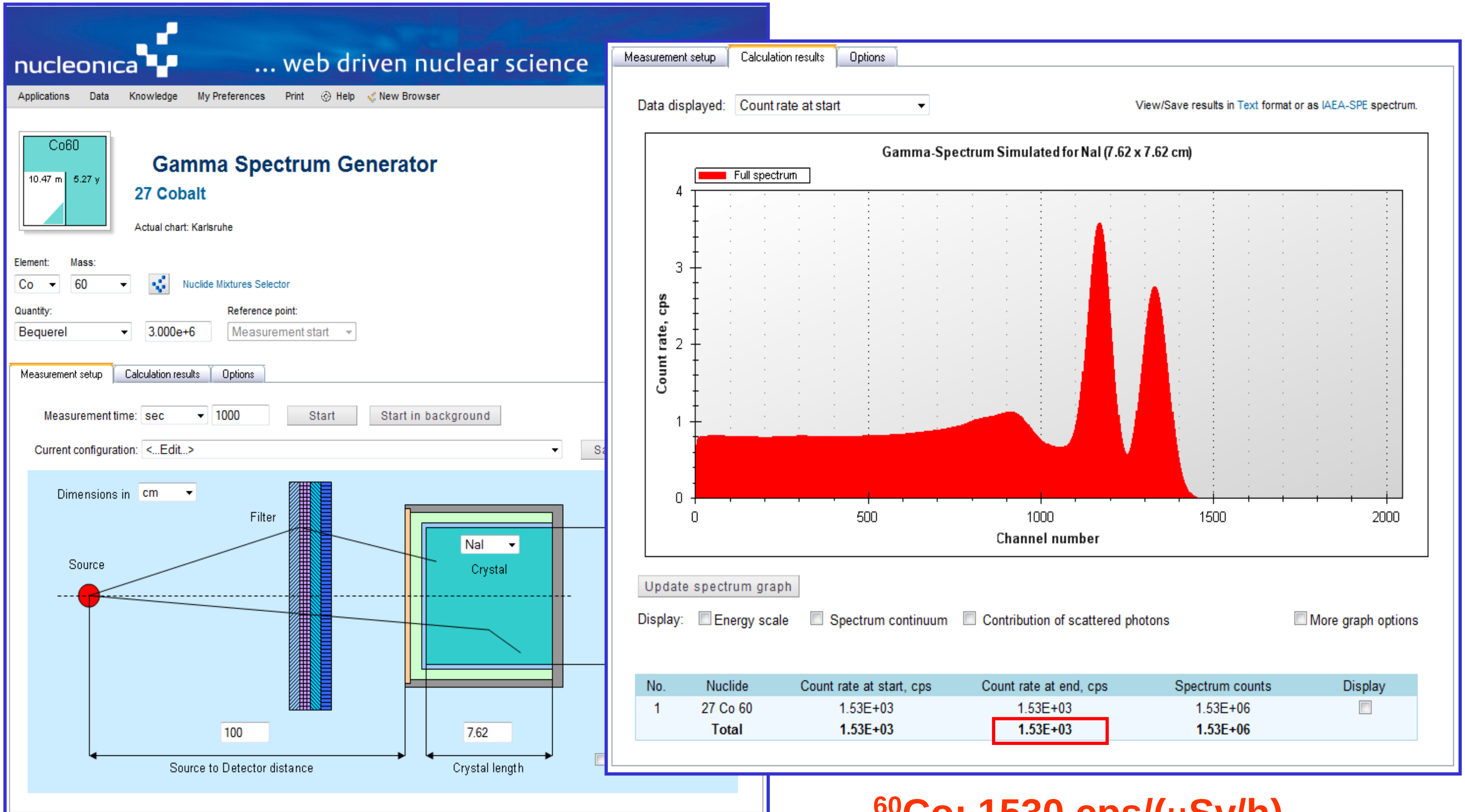
Step 2: Using GSG, evaluate the count rates for the 240 MBq ^{241}Am and 3 MBq ^{60}Co sources at 1 m distance. Assume a scintillation detector with a 3'' x 3'' NaI crystal.



^{241}Am: 37300 cps/(µSv/h)

Required ≥ 10000 cps/(µSv/h)

GSG: A simple application example



^{60}Co: 1530 cps/(µSv/h)

Required ≥ 1000 cps/(µSv/h)

Thanks !

nucleonica